OL. XXXIII. — No. 9. SEPTEMBER 1956.

Monthly Bulletin of the International Railway Congress Association

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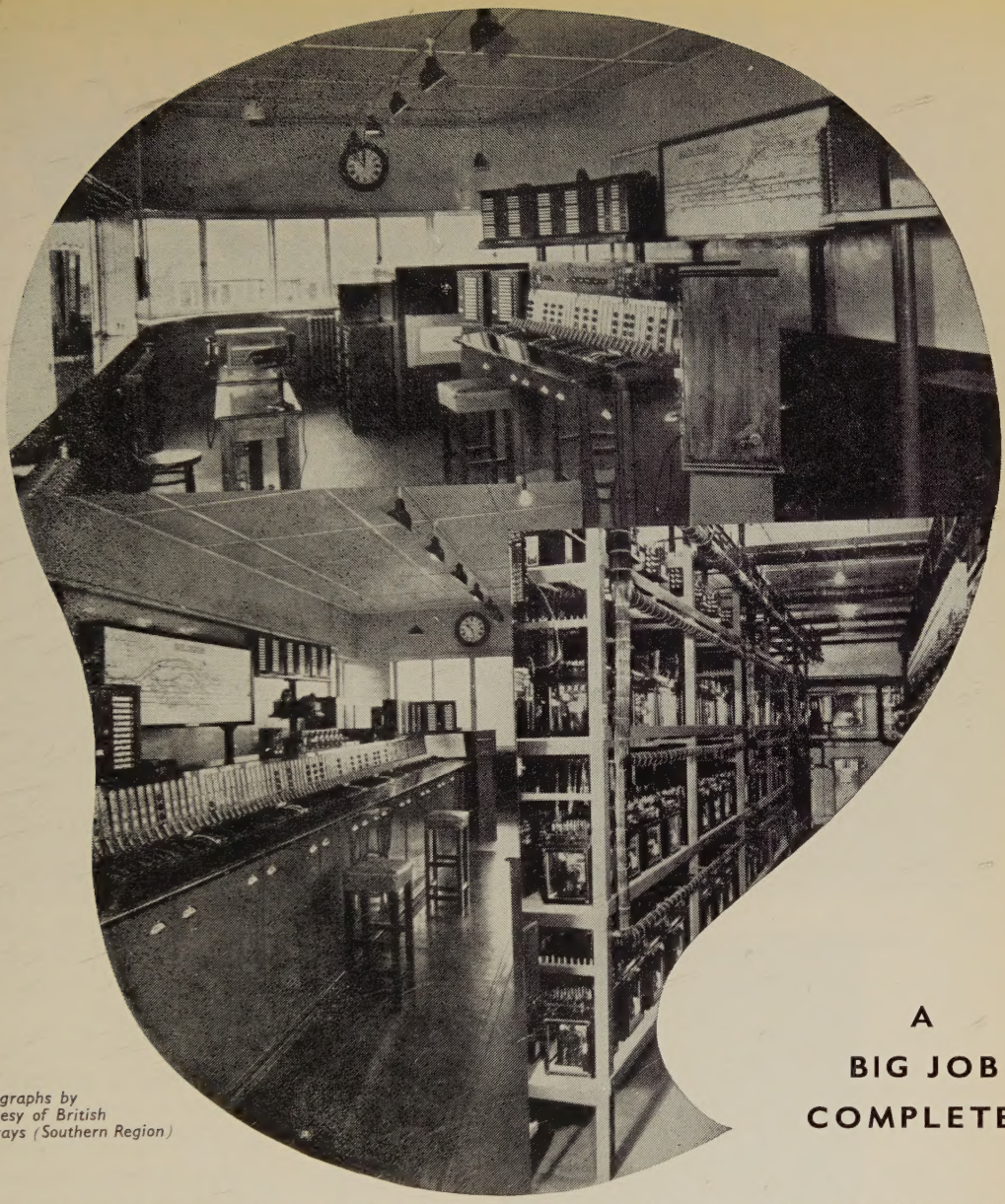

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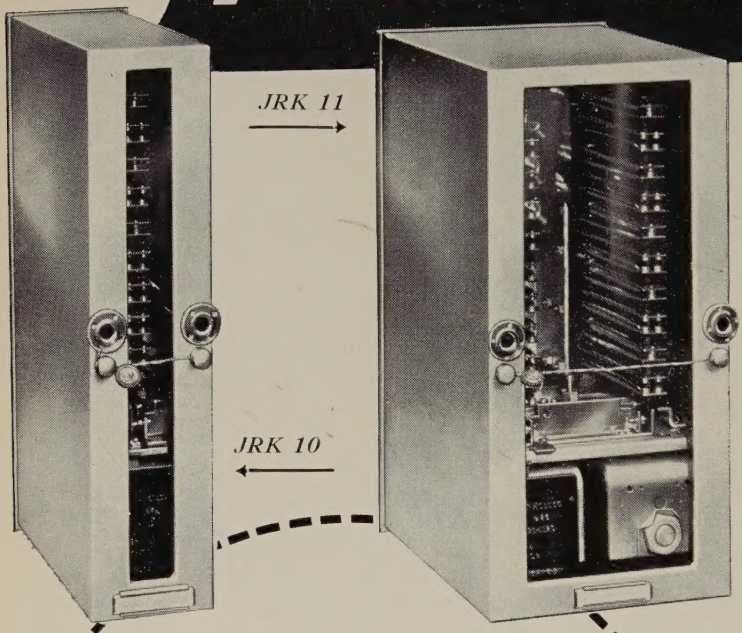

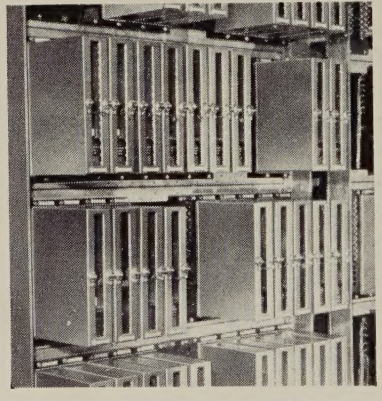

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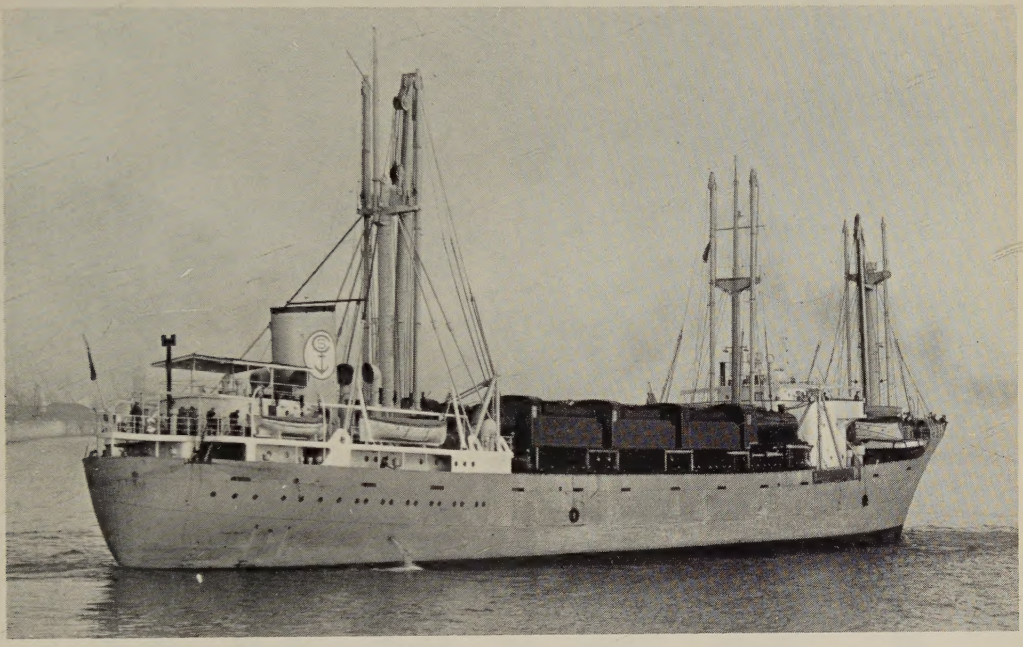

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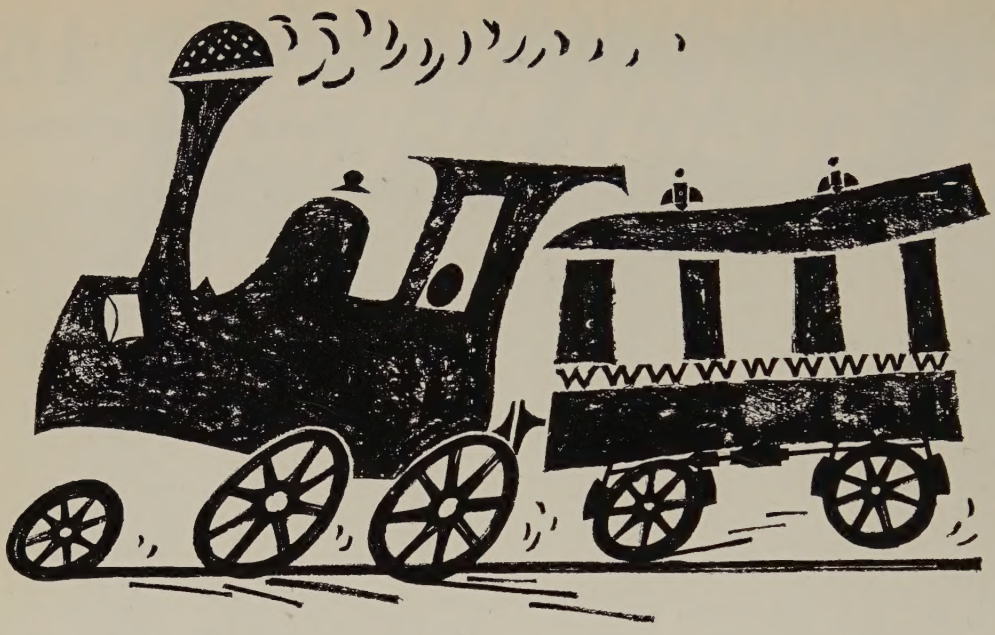

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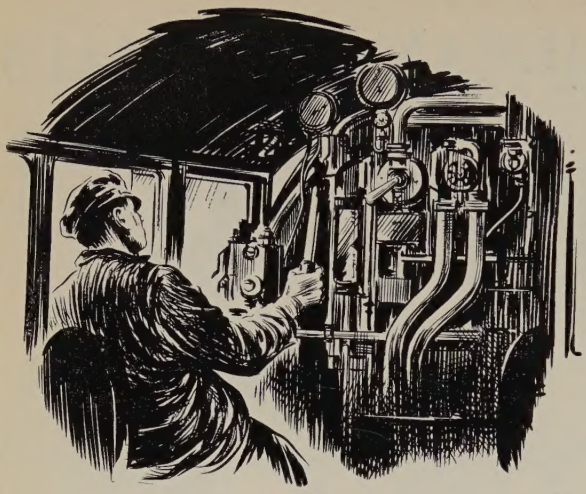

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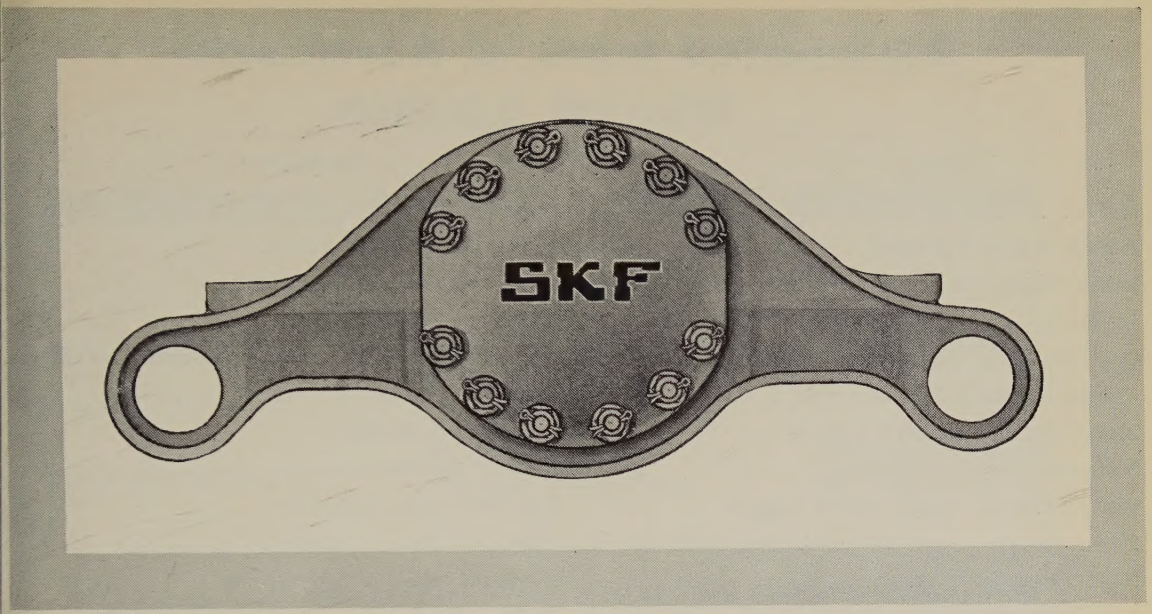

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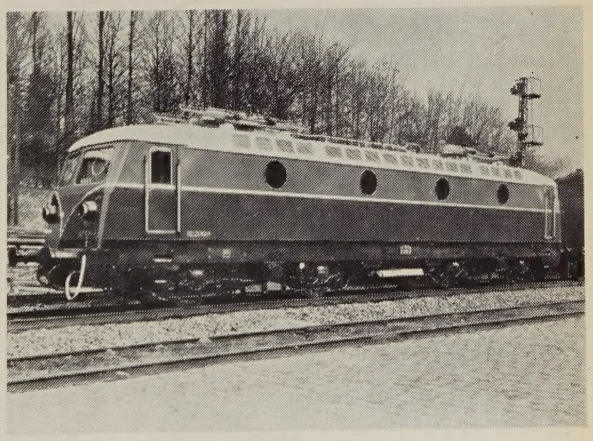

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MONTHLY BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

(ENGLISH EDITION)

PUBLISHING and EDITORIAL OFFICES : 19, RUE DU BEAU-SITE, BRUSSELS

Yearly subscription for 1956 : { **Belgium . . . . . 700 Belgian Francs** / **Universal Postal Union . . 800 Belgian Francs**

Price of this single copy : 80 Belgian Francs (not including postage).

Subscriptions and orders for single copies (January 1931 and later editions) to be addressed to the General Secretary, International Railway Congress Association, 19, rue du Beau-Site, Brussels (Belgium).

Orders for copies previous to January 1931 should be addressed to Messrs. Weissenbruch & Co. Ltd., Printers, 49, rue du Poinçon, Brussels.

Advertisements : All communications should be addressed to the Association, **19, rue du Beau-Site, Brussels.**

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An edition in French is also published.

Vol. XXXIII. — No. 9. September 1956.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[656 .254 (45)]

Centralized traffic control on the Bologna junction network,

by Dr. Ing. F. Tolotti,

Inspecteur en Chef supérieur au Service des Installations Electriques des Chemins de fer de l'Etat Italien.

1. The Bologna junction network of lines.

Six main lines converge on Bologna where they form a junction system. Three come from north-west, north and north-east, namely from Milan, Verona and Venice, respectively, and three others from south and south-east, namely from Pistoia (the old line from Florence), from Florence (new line D.D.), and from Ancona.

The configuration of this junction is governed, firstly, by the fact that the lines mentioned above converge directly on Bologna Central Station (except the line from Pistoia which branches off the Milan line at S. Viola) and, secondly, by the fact that the lines are linked with Bologna's marshalling yard, San Donato, by means of a long loop, known as « Belt Line » (Fig. 1).

Two other stations forming part of this system are the goods yards « Bologna Ravone » (the former marshalling yard) and « Bologna Arcoveggio ». The former is in direct connection with the lines from Pistoia, Milan and Verona (via S. Viola Junction) and Venice (via Battiferro and Agucchi Junctions), whilst the Ravone traffic from Ancona and Florence D.D. uses the Belt Line. Arcoveggio is exclusively reached via the Belt Line.

The junction system forming the subject of the present article is limited by the first station encountered on each of the six lines radiating from Bologna. These stations are therefore, in the following, collectively called « entrance stations ». They are (from left to right in Fig. 1), the stations Borgo Panigale, Lavino, Tavernelle, Corticella, Mirandola and S. Ruffillo.

Beyond these stations, the lines from Milan, Verona, Venice and Ancona are equipped with manual block system and the line from Florence with automatic block system, whilst there is no electric block system on the line from Pistoia.

The entrance stations Lavino and S. Ruffillo are equipped with electrically operated signal cabins with free levers, those of Tavernelle and Mirandola with electrically operated signal cabins with individual levers, and those of Borgo

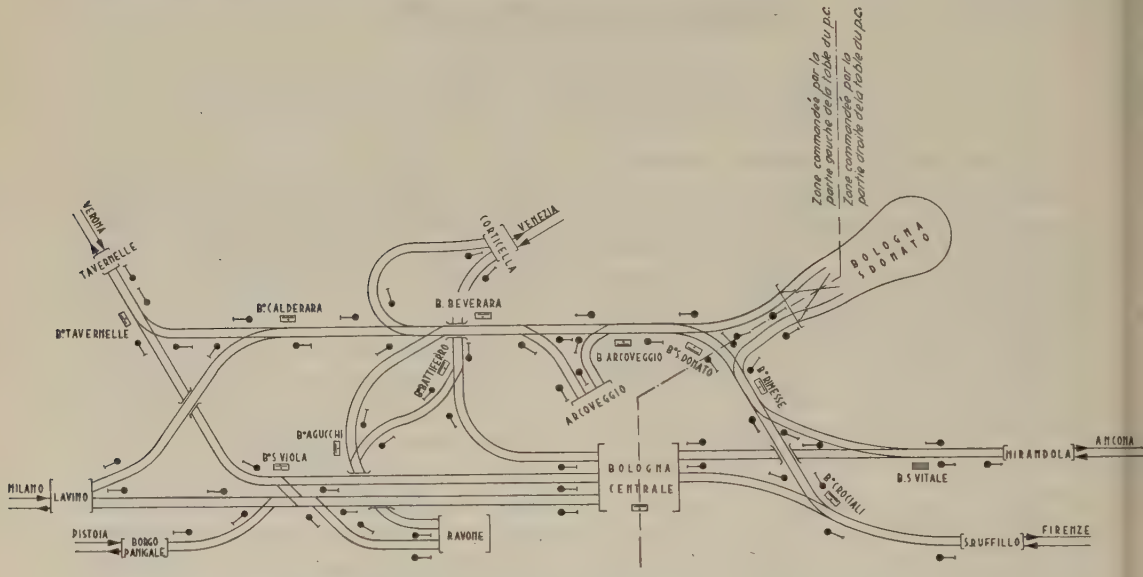
Panigale and Corticella simply with mechanically interlocked boxes.

At Bologna Central Station, where the pre-war installations had been completely destroyed, two electrically operated signal cabins with route levers were taken into operation in 1950 and 1951. At S. Donato marshalling yard, by way of completing a programme initiated before that period, six electrically operated cabins with individual levers plus a hump signal cabin with automatic combination of siding selection and rail brakes have been installed in recent years.

The signalling installations on the sections between the entrance stations and terminal stations, including the Belt Line and its junctions, will be described separately, being the main subject of our description.

All the signals are of the search-light type.

The junction system and the six lines feeding it are completely electrified with 3 000 Volt D.C., after the electrification of the Bologna-Ferrara (Venice) line in 1954.


Zone commandée par le poste de la tête du p.c.
Zone commandée par le poste de la tête du p.c.
VENEZIA
CORTICELLA
B. BEVERARA
B.CALDERARA
B.TAVERNELLE
TAVERNELLE
BOLOGNA S.DONATO
B. ARCOVEGGIO
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BOLOGNA CENTRALE
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ANCONA
MILANO
LAVINO
PISTOIA
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porary signalling installations, consisting of ground-level boxes with manual block apparatus. At the same time, however, a complete solution was decided envisaging power-operated signal cabins with individual levers for all junctions, manual block working and a remote control and indication system, designed to control the traffic on the sections of line forming part of the junction system by means of authorizing devices acting on the signals of junctions and stations.

This system was designed to improve the particularly unfavourable conditions of this network which is formed by a great number of closely spaced junctions with signal cabins that had to be connected by manual block working.

In practice, there is, on lines with short manually worked block sections, the drawback of having too short a warning of the arrival of a train so that the signals are cleared rather late. Alternatively, with a different arrangement, the signals are cleared prematurely so that, in the case of a series of junctions, a certain number of points ahead of the train are locked too early, to the detriment of flexibility of operation. Moreover, if two trains not running according to timetable must use conflicting routes, the junction signalman must use his discretion as to which trains to stop. This is a task which calls for information from an official conversant with traffic conditions, all the more so, if the junction is not isolated, but is one of a chain of similar junctions.

The Italian State Railways were thus confronted, fifteen years ago, with their first opportunity to introduce remote control with a view to ensuring the regulation of traffic controlled by local officials by means of power-operated signal cabins and manual block working.

The works undertaken for this purpose were halted in 1943, shortly after they had commenced.

The matter was again taken up in 1950, at a time when the new signal cabins for Bologna Central and Bologna S. Donato as well as the cabins and automatic block working on the direct line to Florence were already at an advanced stage of completion, and it only remained to complete the equipment of the junction system concerned.

But the problem arose in a different way. In view of the general progress in signalling technique and the greatly advanced development of Centralized Traffic Control (C.T.C.) in America, which had meanwhile taken place, it was now envisaged to introduce a complete C.T.C. system which could normally be operated from a central control room without requiring the presence of signalmen in the junction cabins.

For this purpose, it was necessary to provide, at the junctions, signal cabins of the « all-relay » type with automatic order cancellation, instead of the cabins with individual levers envisaged in the original programme. Moreover, it was necessary to equip the sections of line of the junction network with automatic block system.

As far as the first point is concerned, and in view of the fact that, at that stage, merely the buildings of the cabins and the control desks were completed, that these desks could also be used elsewhere and that, according to experience

already acquired, an all-relay cabin would not have cost more than a cabin with individual levers, it was found that the measure then envisaged would not incur additional expenditure.

As far as the automatic block is concerned, it was moreover found that the estimated cost of installation would be amply balanced by staff savings which it would be possible to effect with the new system, and that these savings would in fact exceed the total cost incurred by the automatic block and by the installation of remote control (apart for the cost of the cabins at the junctions and entrance stations which were deemed to be required in any case).

In estimating these savings, account was naturally taken of the need to increase the maintenance personnel and of the advisability of keeping on call an operating team ready to intervene in case of trouble, the composition and normal utilisation of this team having to be fixed in the light of experience.

A scheme for remote control, designed to permit a more flexible adaptation to operating conditions, was therefore found to be most suitable, also from an economic point of view. It was therefore decided to adopt this system, but to preserve, at the same time, the possibility of local operation in exceptional circumstances.

3. **Description of the installation as a whole.**

The installation brought into being consists of :

(*a*) a central control room;

(*b*) 21 local cabins, comprising eleven junction cabins (some of them controlling a group of simple junctions), six cabins at entrance stations and four at terminal stations (Fig. 1);

(*c*) a system of remote control and indication, linking the central control room with the local cabins (this system will hereafter be simply referred to as C.T.C.);

(*d*) the automatic block system extending over all sections of the junction system.

Fig. 2 shows these installations in a very schematic form.

The central control room is worked by a Controller (Dispatcher). It comprises a control desk and an illuminated track diagram.

From this control room, orders are transmitted to the junction cabins and verifications are received from them. The orders are mainly concerned with the setting up of routes whilst the verifications concern the condition of the track circuits, the position of points and signals, and other matters which will be explained later.

In view of the fact that the service might be worked under two main alternative conditions, viz. with or without the manning of the junction cabins, the orders transmitted from the control room and received at the junction cabins either take the form of authorisations acting on the signals, or serve to set up the routes directly, subject to local interlocking.

The central control room has been so designed as to reduce the interventions of the Controller to a minimum. That is why the control by means of levers and buttons relating individually to the routes at each junction, though possible,

is not a normal operation. On the contrary, the duty of the Controller will normally be confined to accepting the trains electrically announced by the station ready to despatch the train to the remote-controlled zone. In some cases, the train must be expressly accepted by the Controller pressing the appropriate button. In other cases, even this action is not required, as the train announcement will automatically progress in the control room apparatus as the train moves on, ensuring the transmission of the appropriate orders on the way. In other words, it is the train itself which selects its route and operates the signals as it approaches the junctions. The Controller will of course intervene if necessary in order to stop or modify these automatic progressions in the exercise of his proper function.

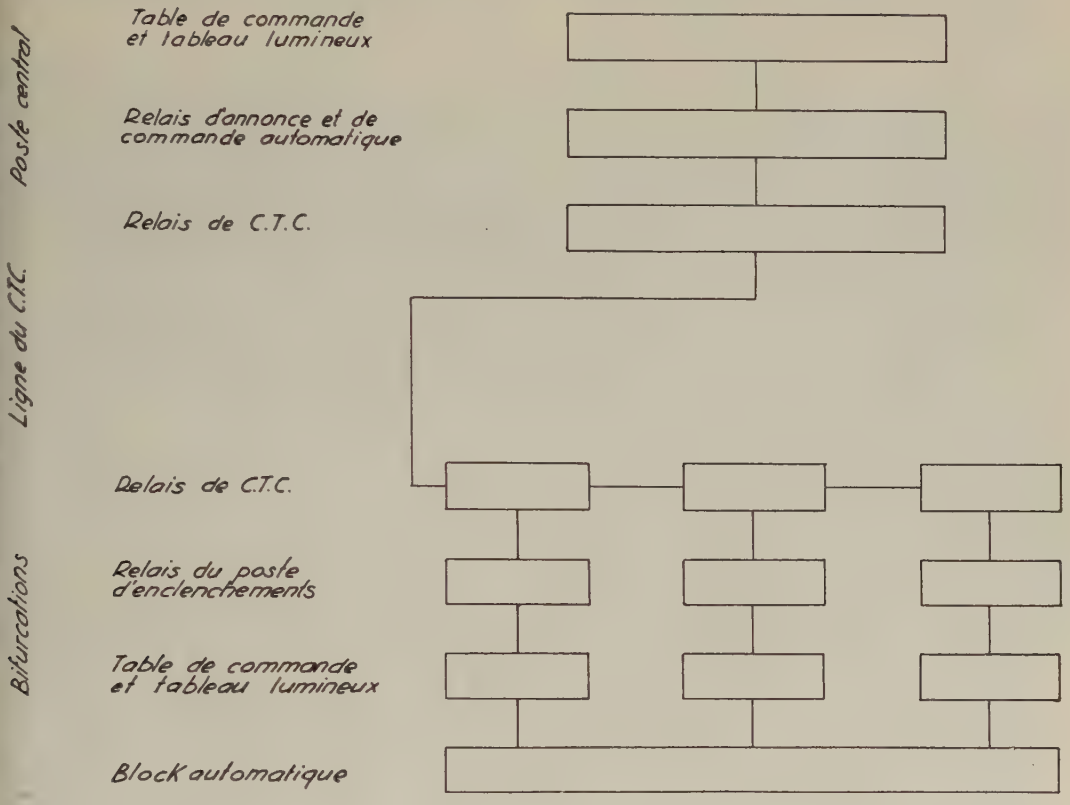


Fig. 2. — General plan of installations.

Explanation of French terms :

Poste Central = central control room. — Table de commande et tableau lumineux = control desk and illuminated track diagram. — Relais d'annonce et de commande automatique = announcer relays and automatic control relays. — Relais de C.T.C. = C.T.C. relays. — Ligne du C.T.C. = C.T.C. line. — Bifurcations = junctions. — Relais du poste d'enclenchements = interlocking relays. — Block automatique = automatic block.

The eleven junction cabins are of the

all-relay type and normally remote-controlled. They are, however, equipped with a small control desk and a small illuminated track diagram so that they can be locally operated if necessary, e.g. in the case of important maintenance works, a breakdown in the remote control system, etc. For this purpose, a special device permits to cut out the direct operation of the signals by the authorisations of the Controller.

The ten signal cabins of the entrance stations and terminal stations are equipped with a panel carrying the buttons by which the trains about to enter the remote-controlled zone are announced to the control room, and with train announcement indicators for the trains in the opposite direction, i.e. the trains about to leave the zone.

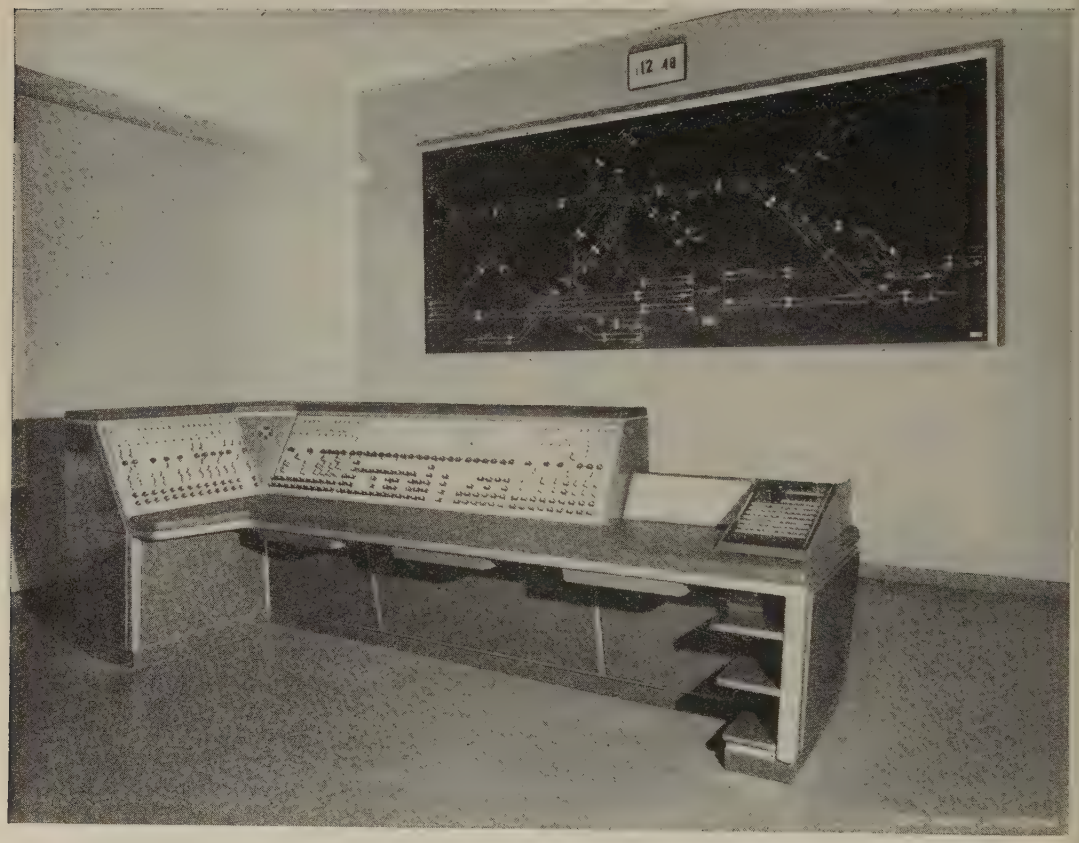


Fig. 3. — Interior of central control room.

The safety of all movements is perfectly ensured by the interlocking at the local cabins and by the automatic block system. Remote control and remote indication have therefore no direct bearing on the safety aspect.

4. Control room : control desk and illuminated diagram.

The control room is installed in the passenger building of Bologna Central Station, in a room immediately adjacent to the boxes of the Dispatchers controlling by telephone the traffic on the converging main lines (Fig. 3).

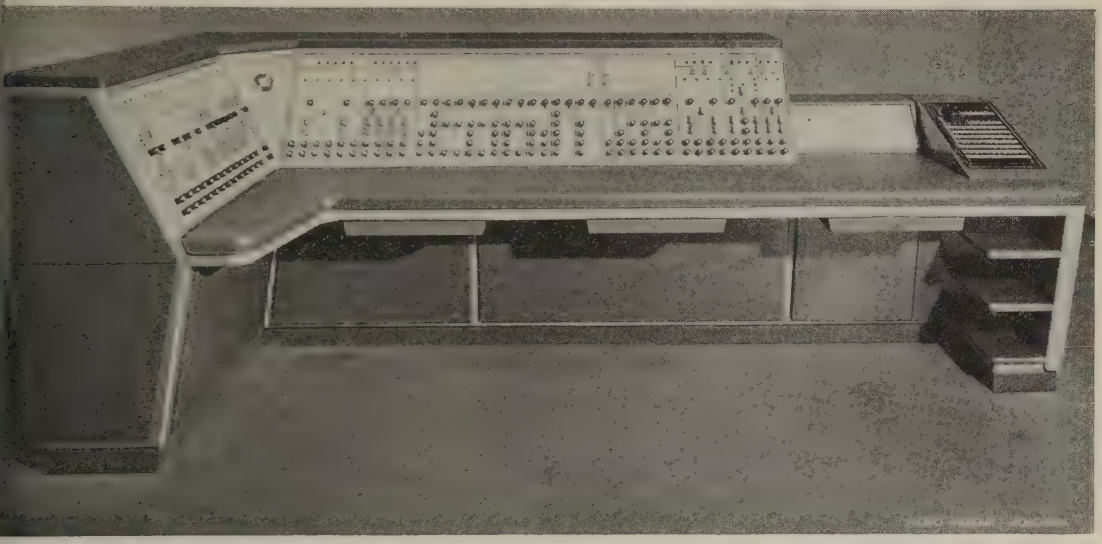


Fig. 4. — Control desk.

The relay room is located below this room (Fig. 9).

The control desk (Fig. 4) has been so designed that the service can be controlled either by two men or by one, according to the intensity of traffic at different times of the day and year, and in the light of experience.

This desk carries a central panel (Fig. 6) comprising all those control organs to which action can be confined if no particular regulating action is required, i.e. if it is possible, at times of light traffic, to leave the working to the automatic devices already mentioned. This panel is therefore called « automatic control panel ».

On either side of this central panel are other panels which contain the equipment permitting the modification of the above-mentioned automatic progressions and the execution of all operations concerning the junction cabins individually. These panels are therefore known as « individual control panels », although they do not contain buttons for the individual control of points which are always operated by the route controls.

The entirety of these panels is thus divided, by a vertical line drawn at three-quarters of its length from the left-hand side, so that the equipment contained in the two parts thus obtained concerns the installations on the left and right, respectively, of an ideal line con-

necting Bologna Central Station and Bologna S. Donato marshalling yard on the schematic drawing (cf. Fig. 4 and 1).

The purpose of this arrangement is to obtain a logical division between the duties of the officials when there are two of them on duty. It has also necessitated a duplication of the telephone equipment inasmuch as the ringing keys and other accessories are repeated in identical form above the panels and on the right-hand side of the installation.

pears spontaneously for all the signals of a cabin if one of its signals is cleared or does not transmit an indication of the signal lighting to the control room. The indication on the diagram is ensured by simple red or green pilot lights, even for multiple (directing) signals. Distant signals are not repeated.

A track circuit appears in red when occupied. Clear track circuits are repeated on the diagram by white lines which only light up when a route affect-

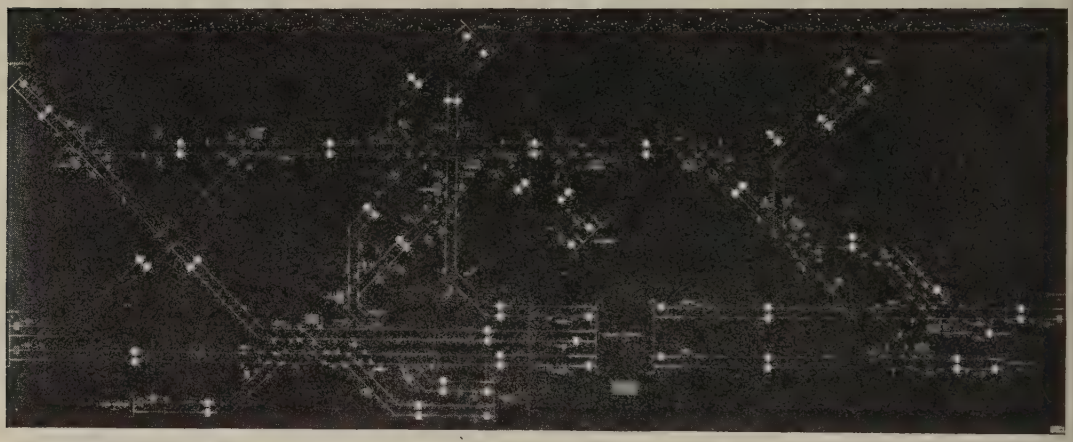


Fig. 5. — Illuminated diagram in the control room.

A single Controller is able to remain seated when working the automatic control panel in the centre of the desk, but he must rise to operate the more remote equipment of the individual control panels.

The illuminated diagram is separated from the control desk (Fig. 5).

The diagram is normally extinct. However, by pressing a button, the position of the signals can be ascertained at any moment. The signal indication appearing these circuits is set up in the control room.

The same applies to the repetition on the illuminated diagram of the position of the points. But these verifications are available at any time in the form of appropriate pilot lamps on the individual control panel.

Another indication given on the illuminated diagram under conditions similar to those applying to the track circuits is that concerning the position of the ap-

proach locking relays of the junction cabins. This position is indicated by an illuminated red or white arrow close to the pilot light of the corresponding signal.

Finally, mention must be made of the square windows arranged on the diagram close to the station departure tracks and near the centres of the block sections. These windows display two luminous code letters identifying the train about to depart from the station or occupying the block section. These letters are the initials of the names of the stations of origin and destination. For example, a train coming from Lavino and destined for S. Donato carries the code letters « LD ».

This device is a great aid to the Controller in carrying out his duties, as it enables him to obtain, at any moment, an overall picture of the movements in the zone.

5. Control room : automatic control.

The automatic control panel of the control room contains sixty-three buttons corresponding to what are known as the « through routes » of the remote-controlled zone, i.e. all the possible routes of trains between stations of origin and stations of destination (Fig. 6).

When a train is announced by a station of origin, this announcement is registered at the control room and brought to the notice of the Controller, firstly by the code letters appearing in the appropriate window of the illuminated diagram by the side of the departure road of the station concerned, and secondly by a white flashlight on the head of the button for the corresponding through route.

If he thinks that the train can be accepted, the Controller presses this button, thus ensuring firstly the transmis-

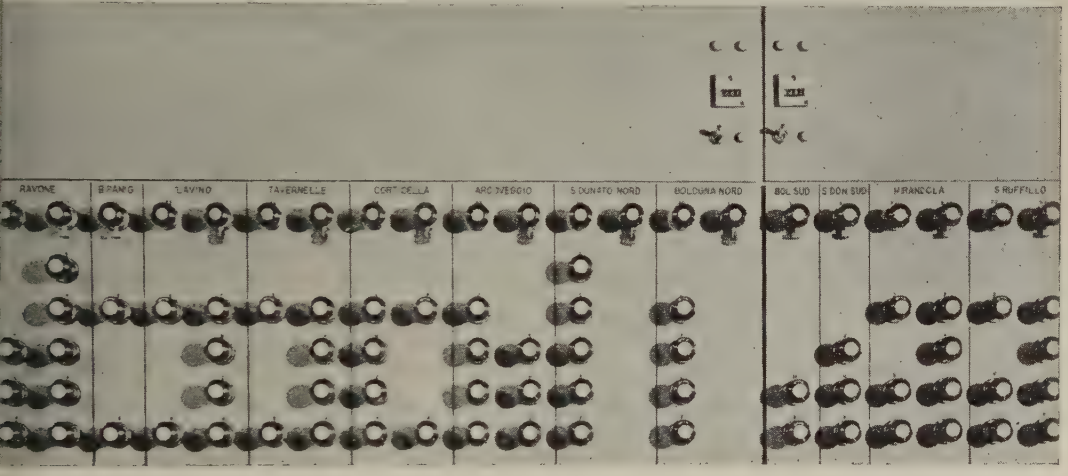


Fig. 6. — Automatic control panel.

sion by remote control of an order to the station by which the train has been announced, and secondly the automatic operation of the apparatus at the control room designed to direct the train to its destination station. The flashlight on the control button then changes into a fixed light.

As far as movements to or from the passenger station are concerned, the Controller is even able to avoid the need for such a response to a train announcement, by establishing a permanent authorisation which he can obtain by pushing the corresponding buttons beforehand and turning them so that they are held in that position.

In view of the fact that the through routes have a considerable length, up to 14 or 15 kilometres for freight trains and up to 9 or 11 kilometres for passenger trains, and that they consist of several part-routes (sometimes five or six), each of which affects the points of a junction cabin, it would obviously be undesirable, from an operating point of view, to set up all these routes at once from one end of the zone to the other. The following method of progression, which applies to the normal case, has therefore been adopted.

When the station of origin, having received the desired authorisation electrically, clears the starter signal, the train announcement is transmitted to the apparatus of the first junction ahead, thus ensuring the setting up, at that junction, of the part-route corresponding to the through route concerned and, in consequence, the clearing of the signal concerned.

Subsequently, as soon as the train has entered the first block section (between the station of origin and the first junction), the train announcement is transferred to the second junction where the desired route is set up and the signal cleared as before.

The train announcement is then passed on at the normal distance of two block sections ahead of the train (e.g. when the train enters the first junction, the signal at the third junction will clear) except of course that, if two trains follow each other at block section interval, the announcement of the train will only affect one section ahead.

But the typical arrangement just described does not apply to all cases. For example, in the case of the longest block sections, the train announcement is passed on only one section ahead. The same applies to the last sections on the Belt Line used by trains about to leave that line, so as to delay as much as possible the setting up of part-routes for freight trains which would delay the working of passenger trains. Finally, certain sections are subdivided by an intermediate relay station designed to obtain a convenient slowing down of the speed with which the announcement travels ahead of the train.

On the illuminated track diagram in the control room, the code letters identifying the trains, though operated by the announcer relays, only appear in the sighting windows in the centre of a block section when this section is occupied by the train.

The authorisation transmitted by the Controller to an entrance station or terminal station can be manually cancelled by pulling out the button concerned.

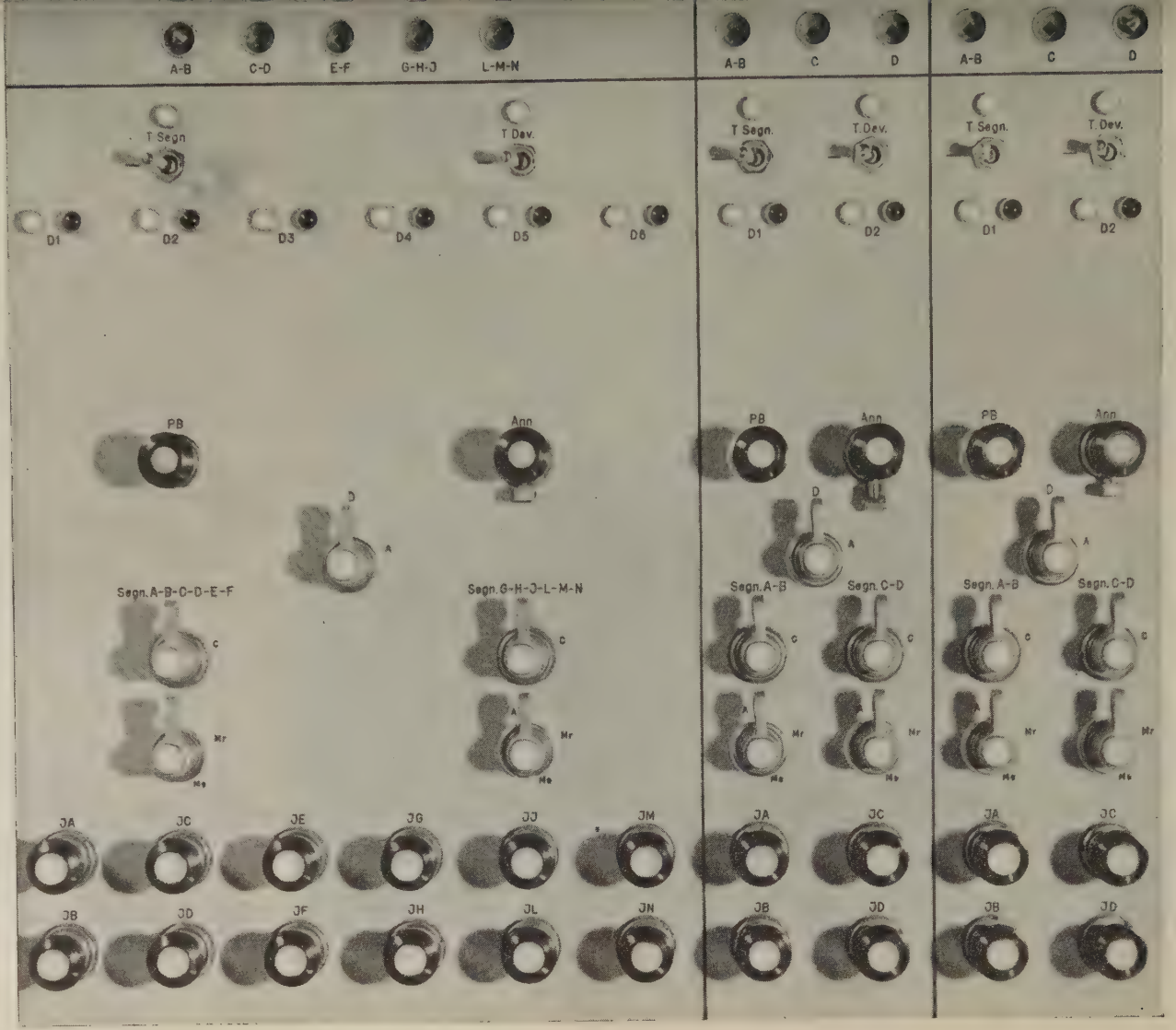


Fig. 7. — Group of panels for the individual control of junctions.

But this cancellation is not operative if the train has already made use of the authorisation and has set the automatic train announcement system in motion.

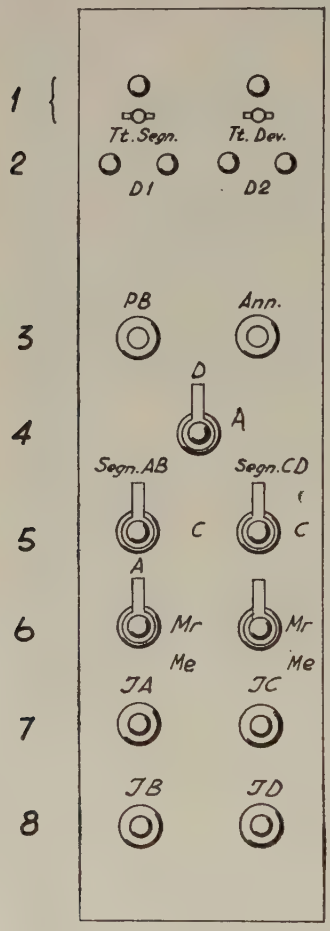


Fig. 8. Details of a panel for the individual control of a simple junction.

6. Control room : regulation and individual control.

The equipment of the individual control panels is grouped in units corresponding to the junction signal cabins (Fig. 7).

Fig. 8 shows the control unit for a simple junction such as junction No. II in Fig. 11. The equipment of this small panel will be referred to below by the number of the row to which it belongs.

Mention must first be made of the switch levers 6, one of which relates to movements in the up direction and the other to movements in the down direction.

As long as such a lever is kept in the position vertically upwards (*A*), and a train announcement concerning the junction (say, junction No. II) is transmitted to the control room, this announcement ensures the transmission, at the earliest possible moment, of the order for setting up the part-route concerned and, thus, for the clearing of the junction signal. Moreover, in the normal case, the announcement is passed on to junction No. III as soon as the train has entered junction No. 1. In other words, if all the levers 6 of the panels concerned are placed in position *A*, the installation works automatically as described in the preceding chapter.

However, if lever 6 (Fig. 8), e.g. the one controlling the down line, is switched to the horizontal position *Mr*, an announcement of a train movement in that direction, received by the junction apparatus, is registered there without operating the remote control. In that case, the Controller must press the button for the desired route (rows 7 and 8) if the order is to be carried out.

If lever 6 is in the *Mr* position, the train annoucement is passed on to the junction ahead (junction No. III) only

when the train enters junction No. II. If lever 6 is placed in the *Mr* position whilst the train announcement had already been passed on automatically to the third cabin, the operation of that lever entails, first of all, the cancellation of the registration at that cabin.

movements. It is in this way that the Controller can exercise his characteristic function of controlling the traffic.

It is even conceivable that the levers 6 of all the units might be maintained in the horizontal position. One would thereby obtain an operating system simi-

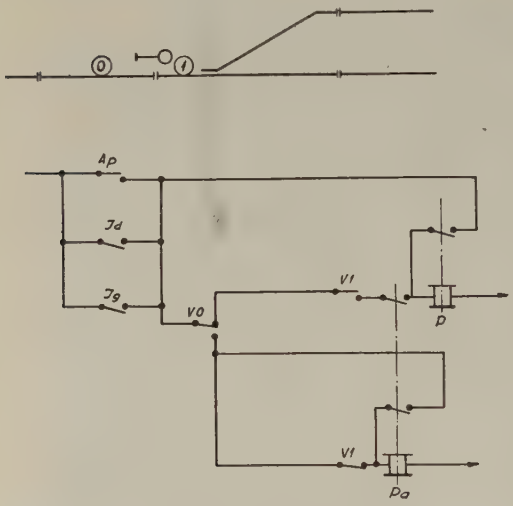
Fig. 9. — Relay room of the central control cabin.

Thus, the timely switching of a lever 6 to the *Mr* position enables the Controller to stop the automatic working of the control room equipment for the signal cabin and the direction of running to which this lever corresponds, and to substitute the direct operation of the routes with a view to determining at will the sequence of two or more conflicting

lar to normal C.T.C. installations, i.e. with orders for the setting of points and signals given by the Controller every time. As already stated, the solution does of course include route control and the luminous repetition of the train description.

The levers 6 can also be placed in a third position, *Me,* vertically downwards.

When the levers are in this position, the control is exercized by means of buttons 7 and 8, independent of any train announcement. This system is provided in order to permit the operation of traffic if the announcement system should break down, or if it is necessary to change the destination of trains after they have entered the zone. With this device, it is also possible to test the working of the apparatus of a signal cabin at any time.



Ap = approach locking relay.
Jd, *Jg* = route control relays (*d* = right, *g* = left).
V0, *V1* = track circuit relays.

Fig. 10. — Circuit of passage relays (local cabin).

Continuing the examination of the unit shown in Fig. 8, one finds the levers 5 destined for the emergency closing of the signals for up and down trains respectively. These levers, when placed in the horizontal position, cause the signal to display the danger aspect if it happens to be clear. Moreover, if a route order is transmitted while lever 5 is in the closed position, the order is carried out at the signal cabin concerned but with the signal remaining in the danger position.

The panel in row 4 has a lever *A/D* which, if placed in the horizontal position *A*, authorizes the local operation of the cabin concerned and, if placed in the vertical position *D*, cancels such an authorization previously given.

In row 3 are two buttons. If the button on the left (*PB*) is pressed, it ensures the priority, at the local signal cabin concerned, in the transmission of remote control orders, overriding for this purpose the predetermined order set up by the C.T.C. installation. The button on the right (*Ann*), which must be pulled out, causes the cancellation of the announcements which may have been registered in the control room apparatus in respect of the local cabin concerned.

Finally, in the first two rows, the unit carries the pilot lamps indicating the position of points D_1 and D_2, and the devices (bells, optical repetitors and auxiliary buttons *Tt. Segn.* and *Tt. Dev.*) which are in action if the indication of signals and points has not been obtained.

7. Control room : connection diagrams in principle.

The principles peculiar to the installation here examined concern mainly those parts of the apparatus of the control room which are destined for the automatic announcements and controls, that is why in the following, some details of the connections concerned will be given.

The automatic working of the above-mentioned devices is based on the registration of the passage of trains at predetermined points, which are mainly points immediately behind the signals concerned.

Since a faulty indication of the passage of a train will naturally cause the system to work badly, with very irritating effects on the regular working of traffic, the passage is not registered merely by the occupation of a track circuit, but by the verification of the occupation and the clearing of two consecutive track circuits at two successive moments after the signal has been cleared.

This function is assigned to two relays of the local signal cabin. Fig. 10 shows the circuit of these relays registering the passage of the train at the joint separating the track circuits 0 and 1 which follow each other in that order in the normal direction of running. Relay *P* is the passage relay, *Pa* an auxiliary relay, *Ap* the approach locking relay. When, after relay *Ap* has dropped, track circuit 0 is occupied by the train whilst track circuit 1 remains clear, relay *Pa* is excited. Successively, one obtains the excitation of *P*, and thus the registration of the passage of the train, by verifying the clearing of track circuit 0 and the occupation of track circuit 1.

Contact *Ap* is shunted by a contact of the route relay(s) controlling the signal so as to permit the registration of the train passage even if the conditions required for the clearing of the signal are not present.

Relay *P*, when energized, causes a C.T.C. transmission which has the effect of energizing a passage relay at the control room, such as relay P_1 *(II)* shown in Fig. 12. Relay *P* at the local cabin will remain sticked up until relay *Ap* is re-excited, which will happen, naturally after it has been cleared by the train, as soon as the control room will have transmitted a C.T.C. cancellation of the route order previously transmitted. Finally, once more through C.T.C., control room relay P_1 *(II)* is de-energized.

The circuits at the control room are shown, in simplified form, in Fig. 12 in respect of junction No. II of the system which is shown, in equally simplified form, in Fig. 11.

The group of circuits marked 1 in Fig. 12 is that of the passage relays *P* just discussed.

Group No. 2 concerns repeater relays *Pbis* with delayed excitation, repeating the passage relays.

The relays *P* and *Pbis* have the main function of controlling the announcer relays *A*, shown at the circuits of group No. 6.

Let us, for example, examine relay A_{B-C} *(II)* (in Fig. 12, group No. 6, on the right) which announces to junction No. II (Fig. 11) a train coming from station *B* and destined for station *C*. The excitation of this relay, which is subject to the previous excitation of relay A_{B-C} *(I)*, i.e. the announcement of the train at the previous junction (junction No. I), is governed by relay *Pr (B — I)*, a relay which registers the excitation of relay *Pbis* relating to the departure side of station *B*. This action of *Pr (B — I)* only takes place when the signal protecting junction No. I on the side of station *A* is in the clear position, i.e.

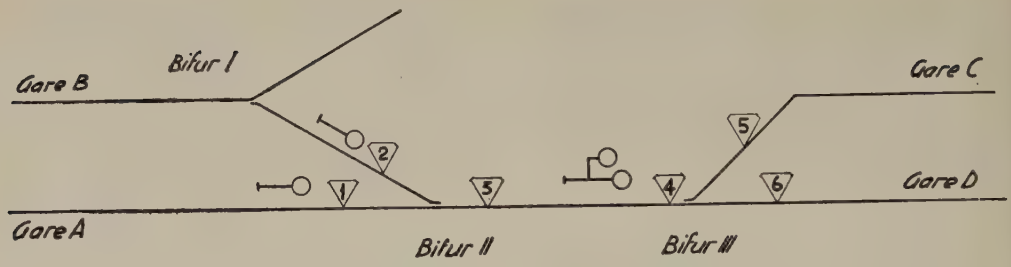


Fig. 11. — Simplified plan of a group of junctions.
Gare = station. — Bifur = junction.

Signification of the symbols used in Figure 12.

P	=	passage relay.
Pbis	=	passage repeater relay.
Pr	=	passage registration relay.
Ann	=	cancellation relay.
B	=	announcement blocking relay.
A	=	announcement relay.
I	=	route relay.
$P_1(II)$	=	passage relay corresponding to point 1 (fig. 11, in a triangle) of junction No. II.
Pr(I-II)	=	passage registration relay corresponding to the movement between junction I and junction II.
$A_{A\text{-}C}$ *(A)*	=	announcement relay of station *A* for the through route between stations *A* and *C*.
$A_{B\text{-}C}$ *(II)*	=	announcement relay of junction II corresponding to the through route between stations *B* and *C*.
$J_{1\text{-}3}$ *(II)*	=	route relay between points 1 and 3 (fig. 11 in triangles) of junction II.

relay *Sv (I)* energized. This is the announcement normally operating two sections ahead of the train, as has already been explained. In the case where such an announcement could not be passed on (non-fulfilment of the conditions for clearing the signal at junction No. I), the excitation of the relay A_{B-C} *(II)* under examination is ensured by the passage relay *P (I)* of junction No. I. One thus obtains the announcement only one section ahead of the train. Relay A_{B-C} *(II)* will then remain up until the train has arrived at junction No. II, and P_2 *(II)* is operated.

Everything happens in the same way with the announcements at this junction No. II of trains coming from station *A* (e.g. relay A_{A-C} [*II*]), except that as far as the announcement two sections ahead is concerned, this is replaced by the announcement at the clearance of the starter signal of that station (excitation of relay *Sv* [*A*]).

Group 7 of the circuits is that of the route relays I which causes the transmission by C.T.C. of the route orders to the local cabins.

It will be seen from the diagram that, when lever *AM* of junction No. II (one of the levers 6 of the unit shown in Fig. 8) is in the *A* position, the excitation

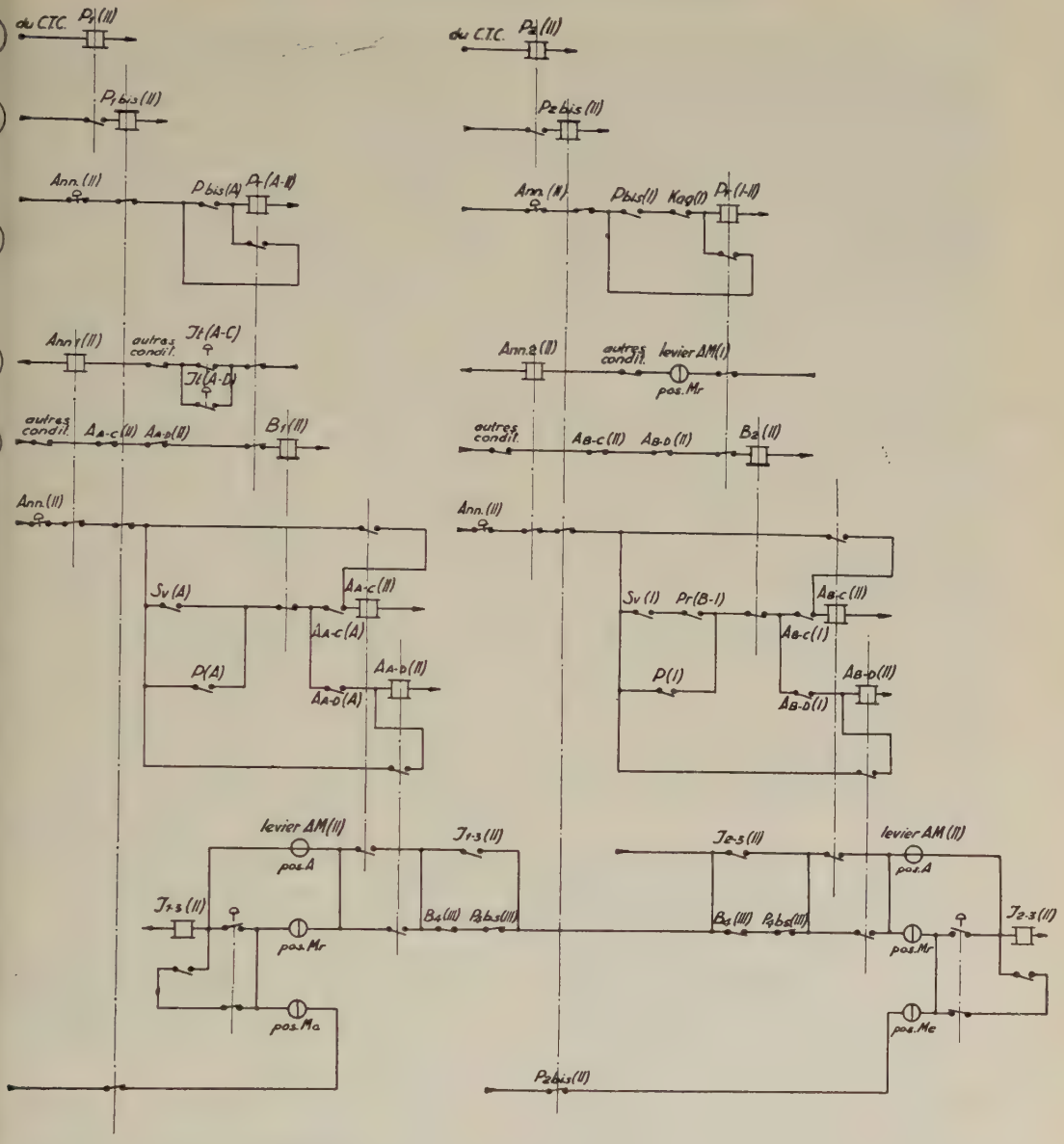


Fig. 12. — Simplified circuits at the control room, related to the example of figure 11.

of an announcer relay, e.g. of A_{A-C} *(II)*, directly ensures the excitation of the route relay, i.e. I_{1-3} *(II)* in the case chosen as an example, which controls the route between points 1 and 3 of this junction (Fig. 11, figures in triangles) : this is the automatic working of the installation. If lever *AM* is, however, in

the *Mr* position, the operation of $I_{1\sim3}$ *(II)* only becomes effective when the button corresponding to this route has been pushed (buttons 7 and 8 of the unit shown in Fig. 8) : this corresponds to the working of the routes by individual control in accordance with the announcement indications (and other conditions referred to later). Finally, if lever *AM* is turned to position *Me,* the individual control of the routes is ensured independently of any condition.

It is now necessary to explain the circuits of groups 3 and 5 which play a subordinate part but are indispensable to the correct working of the system.

In practice, it is necessary to take into account that, in the installation here examined, the announcer relays are controlled by the passage relays and the signal indication relays, and that the operation of these relays, by means of C.T.C., may take place with a relatively considerable time lag (4.5 ÷ 9 ÷ 13.5 seconds or more) after the working of the apparatus of the local cabins by the trains.

In the circumstances, there might be disadvantages in the working of the announcer system explained above, if no special devices had been provided. For example, it would have been possible to receive, at a junction, the announcement of a second train before the receipt of the indication that the preceding train running in the same direction has passed that point. The time lag in the receipt of such an indication would thus have caused the premature passing on of the second announcement. Train No. I would thus have stolen, as it were, the destination of train No. 2 and might have been misdirected.

It is the very purpose of the relays of circuits 3 and 5 to provide interlockings which prevent the premature passing on of the announcement just referred to.

Relays *Pr,* shown on circuits No. 3, serve to register the indication of the passage. For example, relay *Pr (I — II)* is operated when a train enters junction No. I with its route set for junction No. II, and remains up until this train has cleared the section between the two junctions. This permits, on the one hand, the transmission of the announcement to junction No. III even if the signal at junction No. II is only cleared after the train has already passed junction No. I (see circuit No. 6); moreover, the device sets up a condition which is useful in connection with the interlockings here examined.

Relays *B*, fed by circuits 5 and delayed in dropping off, are known as announcement blocking relays. There is one relay *B* for each signal. They are excited as long as the announcer relays affecting this signal, and the relay(s) registering the passage, *Pr,* relating to the section ending at that same signal, are in the rest position. A contact of relay *B* is connected with the circuit of the corresponding announcer relays (see circuits No. 6) so as to prevent the excitation of these relays if *B* has not been excited beforehand.

In this way, the following two conditions are realized :

— when an announcement has been recorded, no other announcement concerning the same signal can be received;

— it is also impossible for an announcement to be received if a train, even

un-announced, occupies the section in approach to the said signal.

Moreover, in order to avoid that a train passes the point at which it would cause the announcement to be passed on to the cabin ahead, whilst the conditions for receiving this announcement are not fulfilled, a top contact of relay *B* and a bottom contact of relay *Pbis* at the cabin where the announcement is about to be registered, are series-connected in the circuits controlling the route relays I of the signals ahead (see circuit No. 7). The branch circuit with these two contacts is shunted by a stick contact of the relay *I* concerned. In this way, a train cannot lose its announcement as a consequence of the interlocking just described.

8. **Remote control and indication system.**

The C.T.C. system ensuring the transmission of controls and indications is that of type *F*, class *M*, of the « General Railway Signal Company », Rochester, U.S.A.

The installation comprises two central C.T.C. machines which are wholly independent of each other, corresponding in principle to the two zones into which the railway network is divided by an ideal line drawn between Bologna Central station and Bologna S. Donato marshalling yard, i.e. to the same two zones which appear on the control desk as explained in chapter 4 above.

The first of the two machines is connected with eleven field locations, combined in two groups, viz.

— S. Viola junction,
Borgo Panigale station,
Lavino station,
Calderara junction,
Tavernelle junction,
Tavernelle station;

— Ravone goods yard,
Agucchi junction,
Battiferro junction.
Beverara junction,
Corticella station.

The second of these machines is connected with ten field locations, equally combined in two groups, viz.

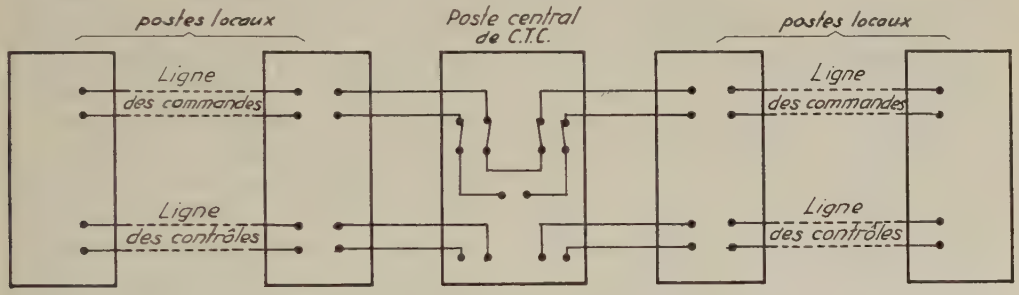


Fig. 13. — Diagram of C.T.C. connections between the control office and field locations.

Explanation of French terms :
Poste central de C.T.C. = C.T.C. control office. — Postes locaux = field locations. — Ligne des commandes = control line. — Ligne des contrôles = indication line.

— Bologna central station,
Arcoveggio goods yard,
Arcoveggio junction,
S. Donato junction,
S. Donato marshalling yard;
— Rimesse junction,
S. Vitale junction,
Mirandola station,
Crociali junction,
S. Ruffillo station.

The control and indication lines, each with two wires, form a distinct 4 wire system. They are included in the telephone cables where conductors had been reserved for this purpose when the electric installations of the network were created.

Each C.T.C. machine has a control line on which the line relays of all the connected locations are arranged in series, and two indication lines (« double-end system ») to which these locations are connected in accordance with the grouping shown above (Fig. 13).

The controls and indications affecting one of the central machines may be transmitted during successive cycles or also simultaneously during the same cycle (« duplex feature »). It is characteristic for the system that, during one cycle, the two indication lines can work together so that, during that cycle, it is possible to transmit controls to a field location and receive indications from two field locations, connected to different lines.

A control transmission consists in ten polarised impulses, viz. six for the code identifying the location called, and four for the orders.

An indication transmission, which is not carried out simultaneously with a control transmission, causes the emission on the control transmission line of a code consisting of all-negative impulses (phantom code) : such a transmission will thus in any case take place in connection with a series of impulses on the control transmission line, in order to ensure the synchronism of the stepper relays at the transmitting and receiving locations. The indication transmitting devices at a field location are so arranged that they either shunt or cut the line, according to the indication to be transmitted, at every impulse, and every interval between impulses on the control transmission line. The indications are therefore obtained by registering, at each half cycle, the verification of the fact whether or not the indication line is energized. An indication cycle thus comprises twenty indications, five of which are used for the identification of the transmitter field location and fifteen for the indications themselves.

The field locations, according to the number of controls and indications to be transmitted, consist of either one C.T.C. location or of a location comprising two or more, up to four sub-locations. Each of the field locations and sub-locations have of course their own identification codes, one for control and another for indication. The identification control codes of the sub-locations of the same field location differ among themselves only in respect of the last impulses of the six of which the identification code consists.

The two tables of Fig. 14 show the utilisation of the control and indication codes for a field location concerned with a simple junction.

9. **Local cabins.**

Fig. 15 shows the whole of a junction cabin, whilst Fig. 16 shows, in greater

	Controls transmitted to the sub-location	
	1	2
1	Field location identification code	
2		
3		
4		
5	Sub-station identification code	Sub-location identification code
6		
7	Up signals emergency to be placed into danger position	Route control
8	Down signals emergency to be placed into danger position	Route control
9	Authorisation for the local control of the junction	Route control
10	Point heating	Route control

Indications received from the sub-location	
1	2
Sub-location identification code	Sub-location identification code
Up line passage Itinerary 1	Down line passage
Up line passage Itinerary 2	
Track circuit	Track circuit
Track circuit	Automatic block
Automatic block	Automatic block
Indication, No. 1 points in normal position	Indication, No. 2 points in normal position
Indication, No. 1 points in reversed position	Indication, No. 2 points in reversed position
Approach locking	Approach locking
Approach locking	Hand operation of points
Track circuit	Track circuit
Track circuit	
Indication, up signal in danger position	Indication, down signal in danger position
Indication, up signal clear	Indication, down signal clear
Indication, up signal in danger position	Local control of junction
Indication, up signal clear	Sector control

Fig. 14. — Tables showing the use of codes for the control transmission and indication of the C.T.C. system.

detail, the small control desk and the small illuminated diagram of this cabin.

These cabins are of the all-relay interlocking type with route setting and automatic cancellation of the route setting.

As already mentioned, these cabins are normally remote-controlled from the control room. When the Controller authorizes the local control of the cabin, the operator in the local cabin acknowledges the authorization by turning a small lever on the desk shown in Fig. 16, whereupon he is able to work the cabin with the route buttons on his desk.

Fig. 15. — View of a junction cabin.

The interlocking includes approach and route locking. The approach lockings are fitted with time release devices which act when a certain time, which can be set for any value up to a maximum of five minutes, has elapsed after the signal has been placed in the danger position.

All connections with the C.T.C. system can be severed by operating another lever which is normally sealed.

If there is a breakdown in the electric operation of the points, these can also be operated by hand on instruction, either by the operator in the cabin or, if the cabin is not manned, by the train staff.

boxes in the close proximity of the points concerned (Fig. 18).

When a junction cabin is not operated locally, the authorization of the Controller, transmitted to this cabin by means of lever 4 of the control unit

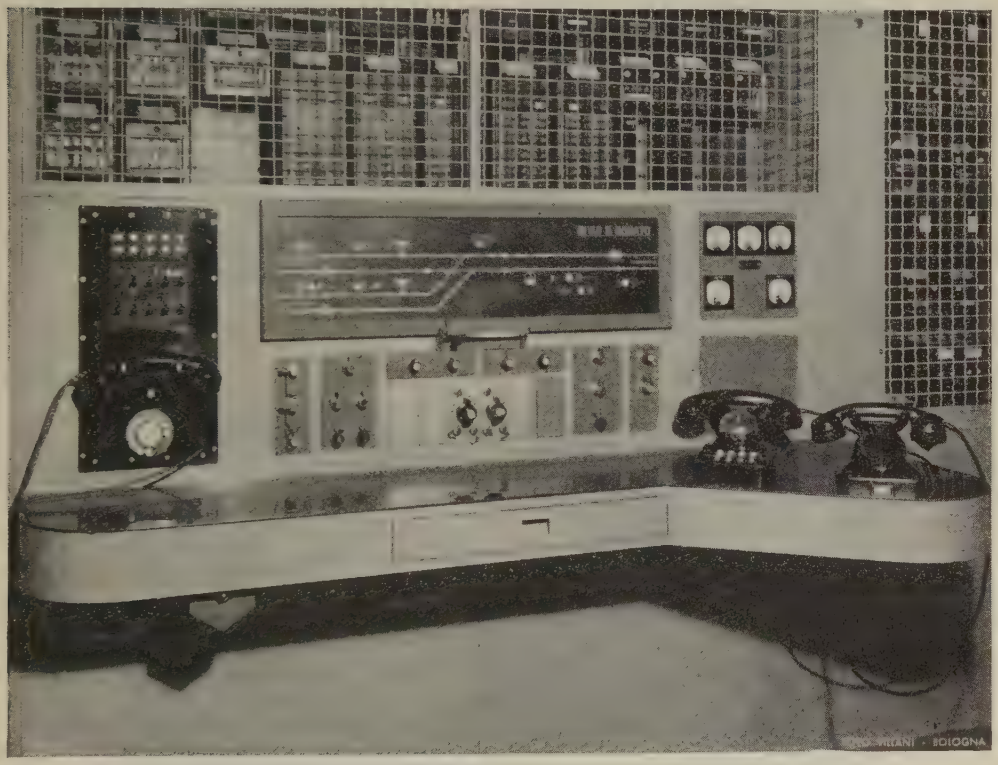


Fig. 16. — Details of the control desk of a junction cabin.

For this purpose, the motors of the remote controlled points are provided with an external lever (Fig. 17) which is normally locked in the horizontal position by a bolt which can be unlocked with a key.

The keys for these bolts are normally kept under electromechanical locking in

shown in Fig. 8, unlocks the electrical locking of the box or boxes concerned, so that the required keys can be extracted and the points can be worked by hand. The removal of a key from the lock brings of course the signals protecting the points to the danger position.

As long as an operator, having ac-

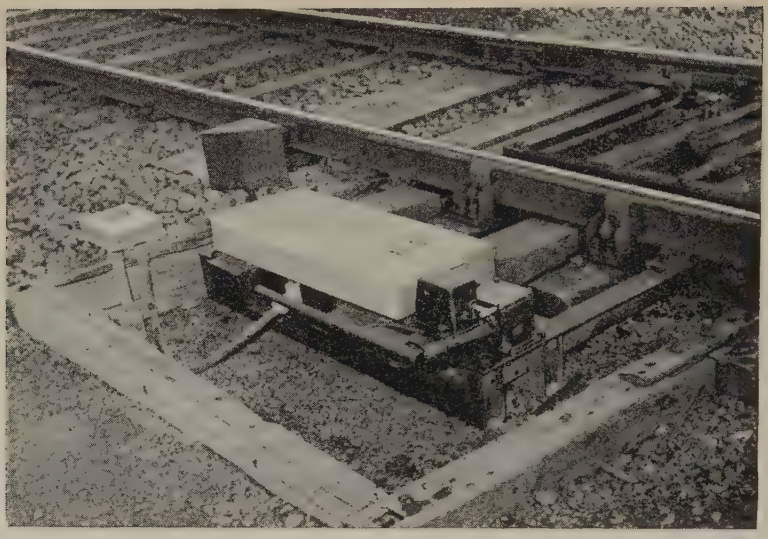


Fig. 17. — Motor for the operation of points, with lever for manual operation.

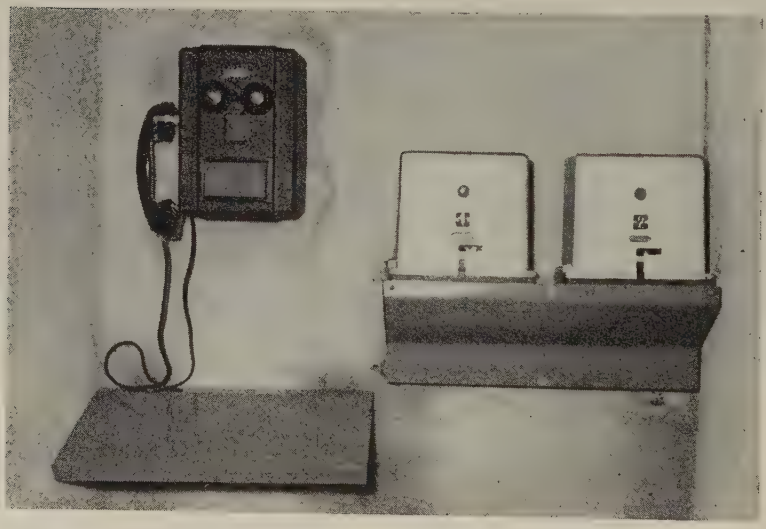


Fig. 18. — Electric locking devices for the keys required for the manual operation of points.

cepted the authorization of the Controller, is working the cabin locally, the unlocking of the electric locks in the boxes is subject to the operation of a special lever on the control desk so that none of the points of that cabin can be

worked by hand without the knowledge of the operator.

10. **Sundry arrangements and features.**

In view of the fact that the signalmen at the old junction boxes were also required to work a certain number of remote-operated level crossing barriers, the general re-arrangement of the installations just described also includes the electric operation of these barriers as part of the route setting at the new cabins. If there is no operator in the cabin, the barriers are thus operated by the automatic apparatus in the central control room, or by the Controller.

The electric indication of the closing of these barriers (which are of the complete type) is interlocked with the junction signals concerned so as to afford complete protection. The indication is also indicated by a pilot light in the control room.

The remote controlled points are electrically heated. The system adopted is the same as that already in operation for several years at Bologna Central Station (where it had of course been reconstructed after the war).

The heating units consist of a resistant wire, insulated by means of small perforated blocks of steatite and contained in a copper tube. Each unit, which is about 4 metres long, is fitted to the outside of the head of the rail.

The current is suplied at 260 Volt A.C. 50 cycles. By means of transformers mounted close to the points, this voltage is reduced to the voltage of 55 V which is applied to the heating units. The two units of one set of points have a power consumption of 2.2 kW.

The heaters are switched in by means of C.T.C. from the central control room.

The automatic block system for the lines within the remote-controlled zone, i.e. on the sections between the stations of origin and the terminal stations (Fig. 1), is of the coded-current type developed by the General Railway Signal Company, Rochester, U.S.A.

The current for the track circuits, which are insulated on the two lines of rail and equipped with resonance-inductive bonds, is supplied at 50 cycles A.C., coded by trains of 75, 120 and 180 impulses per minute on the main lines, but only 75 impulses on the Belt Line where the distant signals were already controlled by cable circuits, and where no cab-signalling is provided.

This system has been adopted in order to use the same installations as on the Bologna-Florence D.D. line where a block system of the same type, with three codes, has been in operation since 1950.

The total length of the sections equipped with automatic block in the Bologna zone is about 80 kilometres (50 miles).

11. **Conclusion.**

The installation described above has been presented under the title of a centralised traffic control system for a group of lines, in view of the fact that it covers a number of relatively distant junctions, each with its own signals, and the points and signals are operated from a single control room by means of a small number of conductors.

If it is further noted that these junctions are spread over a group of lines

realising a railway network and thus having an individual characteristic, that this network has a mean radius of about 10 to 15 kilometres (6 to 9 miles) and that, in particular, the orders and announcements emanating from the control room affect the routes from one end of the zone to the other, it will be seen that the installation also has the character of a power-operated interlocking covering a very extensive zone and using remote control devices, i.e. that it can be likened to a remote-control installation of a zone.

In this respect, the system involves the application of some new principles or, at least, the extension of principles normally applied on a much more reduced scale.

The most important among these features is the very far-reaching application of automatic order transmissions which are such that, in certain circumstances, the train can be handled throughout the zone simply in accordance with an announcement transmitted by the station of origin, and can be directed by means of apparatus operated by the passage of the train itself over the track circuits.

A second outstanding feature is what might me termed « sectional route control » due to the fact that the through route orders registered at the apparatus of the control room are not carried out at once over the whole route, but that the part-routes are set and the junction signals cleared only when the train has reached a given distance from these signals. This device, in fact, fulfils a function complementary to that of the « sectional route interlocking » which ceases to apply to the points already cleared by the train.

[625 .144 .1]

Rails of unlimited length,

by A. Jacops,

Ingénieur principal à la Société Nationale des Chemins de fer Belges.

INTRODUCTION

Numerous recent publications on the subject of very long rails, i.e. rails of unlimited length, reflect the lively interest in this subject on the part of all those anxious to improve the riding quality on the railway and to reduce the maintenance costs. The Belgian Railways, too, have resorted to the use of very long rails, after a period of studies, trials and observations, the conclusions of which are the subject of the present article.

I. Theoretical considerations.

Figure 1 shows a rail OO′ of a very great length L, perfectly free to move at the ends by means of expansion joints without appreciable friction. All the phenomena, which we shall discuss, are supposed to take place symmetrically in relation to the centre point M. We need therefore only concern ourselves with one of the rail ends, say, the one on the left.

Let us assume, on the rail, a point X situated at a distance x from the end O, and, enclosing this point, a short length of rail a, corresponding to the sleeper spacing. If t_0 is the temperature at the time when the rail was laid, t any temperature, and α the expansion coefficient of steel, the short section of rail, assumed to be isolated, will tend to undergo a thermal expansion u_a determined by

$$u_a = a\alpha\,(t - t_0) \qquad (1)$$

It is obvious that, with the movement caused by the temperature rise, a positive movement (real expansion) will take place towards the free end of the rail, and

Fig. 1

that the movements of all the sections of the length a will accumulate to impart a resultant displacement on point O.

If point X is situated in the n^{th} section, there will be n sleepers ahead of the point and $(n+1)$ sleepers ahead of the following section. One thus obtains $n = \frac{x}{a}$, ignoring the decimals.

With the movement produced alternatively at each thermal expansion or contraction, it is necessary to distinguish between the resistance of the rail on the sleeper and that of the sleeper in the ballast. We shall later discuss the magni-

tude of these resistances. But we can state even now that the former resistance is more important than the latter as long as the ballast is movable. As this is the normal and always possible case, and as it also represents the most unfavourable contingency as far as the calculation is concerned, we shall assume that the resistance of the sleeper in the ballast is the only one to be taken into consideration. We shall call it p_a, it being understood that this value applies to a *half-sleeper*.

Supposing, for instance, that there has been a rise in temperature from the moment the track was laid, the rail section which comprises point X is subjected to a stress caused by a force which must overcome the resistance of $(n + 1)$ sleepers, and which is itself acting in the direction of O by displacing n sleepers with a force equal to np_a. If S is the cross-sectional area of the rail, we find that the section concerned is subjected to a stress :

$$\sigma = \frac{np_a}{S}. \qquad (2)$$

This stress tends to provoke an elastic deformation :

$$e_a = \frac{\sigma a}{E} = \frac{np_a a}{SE}. \qquad (3)$$

This deformation, however, is counteracted by the thermal expansion u_a, so that there is a resulting expansion :

$$v_a = u_a - e_a = \left[\alpha(t - t_0) - \frac{np_a}{SE}\right]a. \qquad (4)$$

If the function in brackets were plotted on a graph, one would obtain a stepped curve, the apices of which would be situated on two inclined and parallel straight lines. For a given value of t, this curve would have its maximum for $n = 0$, i.e. at the end O. On the other hand, its ordinate would become zero at a point P corresponding to a specific value of n :

$$N = \frac{SE\alpha(t - t_0)}{p_a}. \qquad (5)$$

As the extent (a) of the steps of the envisaged curve is very small compared with the total length of rail involved in the expansion, it seems convenient to pass from the finite discontinuous representation to the infinitesimal presentation, i.e. practically to mathematical continuity.

In these circumstances, we shall adopt the following new notations :

$$p = \frac{p_a}{a},\ l = Na,\ a = dx,\ v_a = dz,$$

together with :

$$n = \frac{x}{a}$$

already shown earlier.

Instead of equation (2), we thus get :

$$\sigma = \frac{px}{S}, \qquad (2')$$

instead of (4) :

$$dz = \left[\alpha(t - t_0) - \frac{px}{SE}\right]dx, \qquad (4')$$

instead of (5) :

$$l = \frac{SE\alpha(t - t_0)}{p}, \qquad (5')$$

this being the length of rail visibly affected by the thermal expansion.

The stepped curve of equation (4) is thus replaced by a straight line inclined at $\frac{p}{S\ E}$ to an axis parallel to the x-axis and situated at a distance $\alpha(t - t_0)$ from the latter. This is the line OP′ in figure 2, plotted in relation to the horizontal line Y′P′M′ for a given temperature value t. By multiplying dx with the term shown in brackets in equation (4′), we obtain an area element of the triangle OY′P′, representing the deformation of the element with length dx or the elementary

But the same straight line OP′, this time plotted in relation to the x-axis Ox, with its ordinates multiplied by E (which is simply a change in scale), also represents equation (2′) which expresses the elastic stresses prevailing in the rail, and which we shall therefore call the « pressure characterictic ». This is physically limited between the rail end O and a moving point P with abscissa l beyond which, at the temperature t, any tendency towards thermal expansion is annulled by the elastic deformation, the internal stress

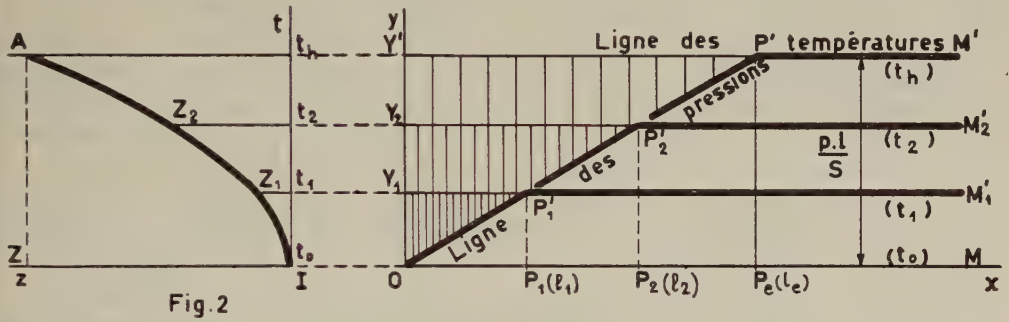


Fig. 2

Ligne des températures = temperature characteristic. — Ligne des pressions = pressure characteristic.

displacement dz experienced by the rail end O due to the impeded expansion of that element. For a temperature t, the total expansion can thus be calculated by the integration of (4′) :

$$z = \alpha(t - t_0)l - \frac{pl^2}{2SE}. \qquad (6)$$

Geometrically speaking, the displacement of point O due to a change of temperature from t_0 to t is measured by the area of the triangle OY′P′ which, though changing in size as a function of temperature, always remains similar to itself.

reaching, in this zone, its maximum value :

$$\sigma_{max} = \frac{pl}{S}. \qquad (7)$$

By introducing into (6) and (7) the values derived from (5′), we find :

$$z = \frac{\alpha l(t - t_0)}{2} = \frac{SE\alpha^2(t - t_0)^2}{2p} \qquad (8)$$

and $$\sigma_{max} = E\alpha(t - t_0) \qquad (9)$$

The horizontal line Y′P′M′ representing this last equation is called the « temperature characteristic », though it also represents (but on a different scale) a constant stress.

Altogether, the magnitude of the internal stress in the rail, at a temperature t, is represented by a broken line such as OP'M'. In rising from t_0 to t, the temperature has successively assumed the values t_1, t_2..., to which correspond the intermediate positions OP'_1, OP'_2..., etc., of the same broken line. Let us now assume that P_e, with the abscissa l_e, is the extreme point which can be affected

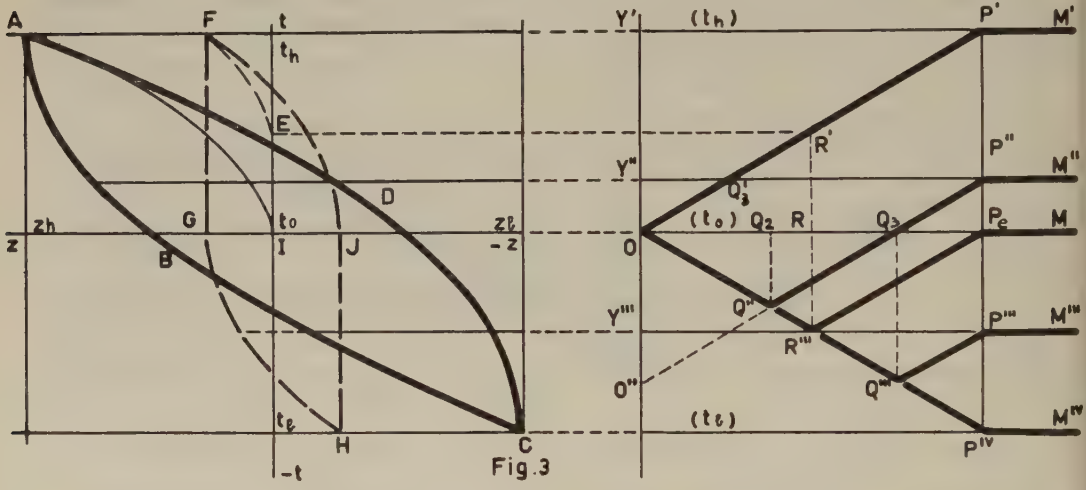


Fig.3

by the « expansion wave », also known as « rail respiration », when the temperature has reached the highest conceivable value t_h.

During this temperature change, from the temperature t_0 at which the rail was laid to the temperature t_h, the value of z varies, in its turn, from zero to z_h, in accordance with the second part of equation (8). This is a law of the second degree which is shown on the left side of figure 2 where It is an axis of ordinates duplicating the original axis Oy, and where the axis Iz of the displacements is drawn in the prolongation of the rail OM.

The z curve is thus a parabola whose ordinates t_1, t_2, ... t_h are, in each case, situated on the extension of the horizontal lines $P_1'M_1'$, $P_2'M_2'$, ... P'M'. With the maximum temperature t_h, this curve reaches a terminal point at A.

When, after having reached the highest conceivable value t_h, the temperature begins to drop, all the parts of the rail, whatever their position, will shorten at the rate of $\alpha(t_h - t)$ and will experience a relaxation $E\alpha(t_h - t)$. The broken line OP'M' will therefore drop as one piece in the diagram and will occupy a position such as O''P''M'' in figure 3, point P'' remaining straight below point P'. However, if the row of sleepers situated between O and any point X was unable to resist a thrust exceeding $y = \frac{px}{S}$ during the compression period, it is now just as unable to withstand, without giving way, a pull in the opposite direction which is analytically a similar term but for the sign. This means that the section O''Q''

of the straight line is non-existent, as the polygonal draught seemingly « adheres » to a straight line OP^{IV}, symmetrical to OP'. If the temperature could drop without interruption from its highest value t_h to its lowest value t_b (assuming t_0 to be the mean value of these two), the « pressure characteristic » would successively assume such intermediate shapes as OQ''P''M'', OQ'''P'''M''' before finally becoming $OP^{IV}M^{IV}$.

The extent of the displacement z of the rail end is always represented (except for the coefficient E) by the area contained between the y axis, the temperature characteristic, and the pressure characteristic, even if the latter is broken as, e.g., OQ''P''. The area concerned can be deemed to be that of triangle O''Y''P'', identical to OY'P' but slipped lower down, minus the area of triangle O''OQ''. The latter represents half the area of triangle $O''OQ_3$ which, in its turn, is identical to $P'P'''Q'_3$. The area of the latter (still apart from the coefficient E) amounts to $SE\alpha^2(t_h - t)^2 : 2p$. The area O''OQ'' will be half that value, i.e. $SE\alpha^2(t_h - t)^2 : 4p$.

At a period of falling temperatures, taking as point of departure the maximum temperature previously reached, we can therefore write :

$$z = z_h - \frac{SE\alpha^2(t_h - t)^2}{4p} \qquad (10)$$

This will be seen to be another parabola, with a vertex at A, but with an ordinate decreasing at half the rate of that of the first parabola IA; in other words, a parabola having a parameter equal to half of that of the curve represented by equation (8). When the temperature changes from the maximum t_h to the minimum t_b, the representative point Z describes the curve A B C, from the greatest expansion z_h at A to the strongest contraction $z_b = -z_h$ at C. It must of course be remembered that, when the temperature line drops below the reference line O M and assumes e.g. the position P'''M''', the apparition of negative triangles such as OY'''R''' must be taken into account.

It is obvious that, with a renewed rise in temperature, the same reasoning applies, and that the movement of O can be represented by a parabolic arc CDA of a shape identical to the first. The closed circuit ABCDA is a kind of hysteresis curve, the area of which represents the work that had to be performed by the heat in order to pull the sleepers in the ballast first one way and then the other.

In order to facilitate the arguments that follow we shall move the origin of the system of coordinates centred on I first to A and then to C so that the two inversed parabolic curves have the common equation :

$$z = \frac{SE\alpha^2}{4p} \cdot \Delta t^2 \qquad (11)$$

We should like to point out specially that curve IA is, in fact, described only once in the life of the rail, namely on the day on which it is laid. The temperature t_0 at the time of laying need not necessarily be the exact mean of the temperatures t_h and t_b. Once the first day is over, equation (11) enables us to break away from this supposition.

One might be interested in the behaviour of a given point R of the rail, situated in the zone between the end O and the extreme point which can be reached by the most complete « respiration », viz. P_e. Let us assume that R is situated halfway between O and P_e.

At the beginning of the first « respiration », when point O is subject to the displacement z according to curve IA, the section of rail surrounding R is, to begin with, simply subjected to compression without carrying out any movement up to the moment when the temperature has become so high that the moving point P, in the course of its migration through the successive positions P_1, P_2, ... etc., passes the point R. At that moment, R begins to move in accordance with the same law as O, and the point in the graph describes the parabola EF.

When the temperature drops, nothing happens at R in the beginning except that the compression is relaxed. Later, when the line OP′ has passed R on its downward move, a progressive extension takes place which continues until the moment when point Q, in the course of migration Q_2, Q_3, ... etc., has arrived at R, corresponding to R‴, the temperature line coinciding with P_eM. By applying the same arguments as applied earlier to OY′P′, we find that the displacement of R is represented first by the straight line FG (no movement), then by the parabola GH, later by the straight line HJ, and finally by the parabola JF.

It will be seen that point Q, just as its particular positions Q_2, R and Q_3 which are projections of Q″, R‴ and Q‴, respectively, plays the same part in the course of the successive respirations as point P immediately after the laying of the rail. As Q passes through R (always in the direction from the end towards the middle of the rail), point R begins to move either to the left (expansion) or to the right (contraction). The greater the distance between R and the end of the rail, the less frequently will R be on the move. During the daily movements of small amplitude, R will be reached neither by the moving point P as the temperature rises, nor by the moving point Q as the temperature drops. It is only occasionally that R will be reached by the « wave » and will undergo a movement, sometimes to the left, sometimes to the right, and so forth.

It may be pointed out that, in practice, the pressure characteristic is hardly ever a continuous straight line (as OP′ in figure 3), or even a simple broken line (as OQ″P″), as the temperature never varies in such a way that it shows a continuous rise or drop throughout the whole range between its maximum and minimum values. In a highly oversimplified form, figure 4 shows some of the shapes, marked by numbers, which this line can assume successively when the temperature, having dropped from its highest maximum, is subject to some fluctuations. It can be clearly seen from positions 2 and 4 that it is possible for compression zones and expansion zones to exist simultaneously in the same rail.

Let us finally examine the case of a rail of a limited length L which is so short that point P, in the course of the « respiration », may reach or tend to pass the centre point M of the rail. The value of l is thus limited to L/2 for a specific temperature t_m, lower thant t_h, which can be determined by equation (5′),

$$t_m - t_0 = \frac{pl}{SE\alpha} = \frac{pL}{2SE\alpha}. \qquad (12)$$

In this case, z assumes a specific value which is determined from equation (8) :

$$z_m = \frac{pl^2}{2SE} = \frac{pL^2}{8SE} \qquad (13)$$

We shall, however, see later on that, in practice, this formula cannot be applied as such.

If the temperature rises further, the rail continues to expand as if it were free, the passive resistance of the sleepers having been overcome.

thereby making the ballast unstable, and other sleepers which move rarely (as has been explained in connection with the discussion of point R) and only over a small distance, so that the ballast, subjected to renewed vibration with the passage of each train, retains its full

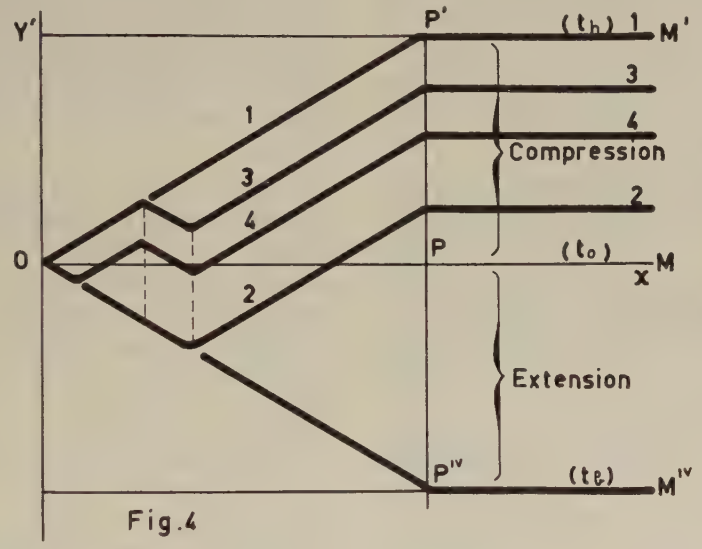


Fig.4

II. Results of measurements.

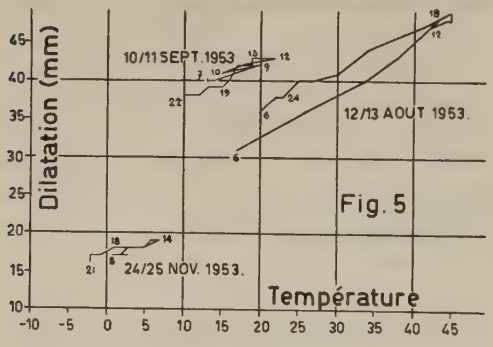
A. *Daily variations.*

All that has been stated is true for temperatures which are assumed to fluctuate between well defined limits, and in the supposition that the ballast offers a uniform resistance throughout. In practice, however, this is far from being the case. If it can, on the one hand, be admitted that, considering the great number of sleepers concerned, the resistance of the ballast is, on an average, almost constant, there are, on the other hand, undeniably certain sleepers which slide frequently and over a great distance, coherence. The temperature, in its turn, fluctuates each day within different and normally very narrow limits. The two branches of the circuit ABCDA in figure 3 can only be regarded as an idealized curve, only small portions of which are applicable to the movements caused by the daily temperature fluctuations.

On the trial section of the Belgian National Railways Company, which was 738 metres long, a number of records were made. During certain periods, the expansion was measured twice a day (close to the points of minimum and maximum temperature, respectively). During other shorter periods, the movement

was measured every hour. Each time, four measurements were taken, corresponding to the four joints marking the ends of the section. These joints were equipped with expansion devices which had practically no friction. An endeavour was also made to observe the measure of rail creep, if any. This movement appeared to be negligible at the time of the trials. Two years later, however, certain expansion devices revealed a displacement of 18 millimetres in the direction in which the trains were running.

We do not intend to reproduce here the complete tables showing the values observ-



Août = August.

ed, but merely some of the most typical diagrams (fig. 5) in which these values are plotted. The figures inscribed all along the curves show the hours of the day.

Our aim was thus to determine the mean resistance of the ballast (p) and to calculate the allowance which the expansion devices must normally be given as well as the gap to be left at the joints when the rails are laid.

Let us revert to figure 3. The two branches of the curve (z, t) on the left-hand side of the illustration correspond to equation (11). However, the extreme values of the daily temperature fluctuation correspond by no means to the complete range of possible variations ($t_h - t_b$).

Let us use the abridged notation t_d for the total amplitude of the daily variations (positive during the day, negative at night) which varies from one day to another, and z_d for the corresponding displacement. It is even possible to observe, on one and the same day, several distinct fluctuations, but these are akin to the daily fluctuations.

In order to determine p, we must find the actual values of t_d and z_d in the daily diagrams and introduce these values into equation (11) for Δt and z. On the assumption that p is constant and that we dispose of a sufficiently large number of readings, we can write the equation concerned in the form

$$p = K \cdot \frac{t_d^2}{z_d} \qquad (14)$$

which seems to allow the supposition that the quotient in the second member is likewise constant. Unfortunately, this is not the case in practice. Among 60 readings obtained in the course of the trials, the value of the quotient varied between 16 and 60 (z_d being measured in millimetres) and had an arithmetic mean value of **34**. The mathematic dispersion reached 13.4, and the relative dispersion 0.4.

Considering these discrepancies, it is pertinent to ask whether the assumption that p is constant is in fact admissible. It seems sometimes that the form $\frac{t_d}{z_d}$ of the quotient is in better agreement with reality The trial results make this value fluctuate

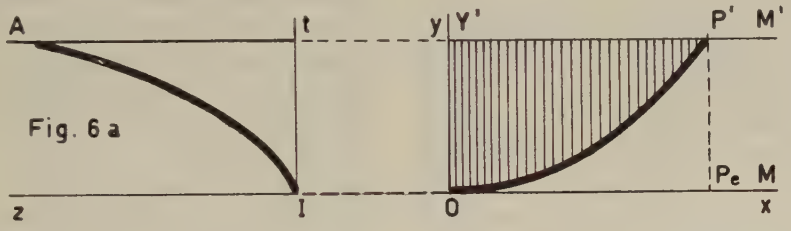
between 1.27 and 7.00, the mean value being 2.87, with a dispersion of 1.14 and relative dispersion of 0.4 as before. This might give rise to the supposition that the two laws are equally probable. But considerations of a physical order preclude the assumption that the expansion should be linear without the slightest resistance on the part of the ballast. Moreover, figure 5 shows clearly the existence of veritable hysteresis curves, though their shapes are rather freakish.

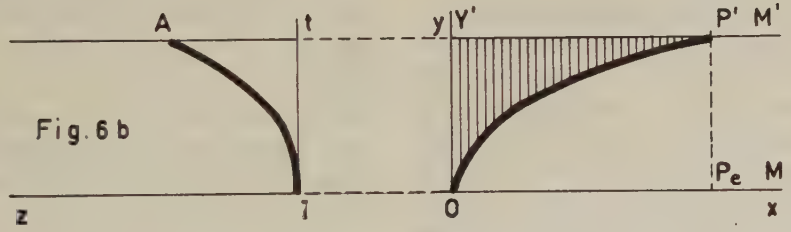
In a general manner, it is possible to write, in analogy to equation (2') :

$$y = \frac{qx^2}{S} \quad \text{hence} \quad SE\alpha t_d = ql^2 \quad (15)$$

Area OY'P' which represents the value of the amplitude z_d (apart from the factor E) is equal to two-thirds of the rectangle OY'P'P_e. Hence :

$$z_d = \frac{2}{3} \cdot l\alpha t_d = \frac{2}{3}\sqrt{\frac{SE\alpha^3 t_d^3}{q}}$$





It would be possible to adopt other working theories, more or less plausible at the outset. Reverting to figure 2, one might assume that the law expressed by the line OP' is not linear but, for example, parabolic such as shown, in two varieties, in figure 6. In case (*a*), the concave parabola would indicate a weak resistance of the ballast against small displacements, and an increasing resistance against the major displacements. This could be expressed in the form of an equation in the following way.

which yields, after combining the constants,

$$q = K' \cdot \frac{t_d^3}{z_d^2} \quad (16)$$

This curve can be discussed in the same way as before : if the parameter q is supposed to be constant, the quotient $\frac{t_d^3}{z^2}$ must also be constant. When substituting the trial readings, we find that this quotient varies between 28 and 343, with

a mean value of 97, an absolute dispersion of 55 and a relative dispersion of 0.57. This solution thus appears to be less justifiable than the first.

In case (*b*), the convex parabola assumes a difficult start but a decrease in the resistance as the movements get under way. Analytically, the curve OP′ would be expressed by the equation

$$y^2 = rx \quad \text{hence} \quad S^2E^2\alpha^2t_d^2 = rl \quad (17)$$

The area of OY′P′ is equal to one-third of that of the rectangle OY′P′P_e hence :

$$z_d = \frac{1}{3} \cdot l\alpha t_d = \frac{1}{3} \cdot \frac{S^2E^2\alpha^3t_d^3}{r}$$

which yields, using abridged terms :

$$r = K'' \cdot \frac{t_d^3}{z_d} \qquad (18)$$

The introduction of the results of the observations yields for this quotient a relative dispersion approaching 1. This solution is therefore even more unacceptable than the preceding one.

We are not of the opinion that other solutions will have a chance of being applicable with greater success. That is the reason why we have retained the first solution, adopting for the quotient the mean value 34 (of the dimension : mm^{-1}). Under these conditions, we can obtain from equation (11) the mean value of the resistance p of the sleepers per metre for one string of rails :

$$p = \frac{SE\alpha^2}{4} \cdot \frac{t_d^2}{z_d} \qquad (19)$$

By introducing for S the cross-sectional area of the Belgian 50 kg/m rail, say 6 322 sq. mm., for E the value of 21 000 kg. per sq. mm., and for α the value found by British Railways in the course of tests specially undertaken for this purpose, viz. 11.52×10^{-6}, we obtain :

$$p = 150 \text{ kg. per metre.}$$

For the two strings of rails together, one thus obtains a resistance of *300 kg. per metre*, and for a single sleeper (with a sleeper spacing of 0.60 metre) a resistance of *180 kg.*

These figures are small if they are compared with those obtained from direct observations. We have thus found, on a short trial section (on non-stabilized ballast) and for a whole sleeper :

without filling between sleepers.	110 kg
with filling, at the beginning of the movement	390 »
with filling, maximum value. .	600 »

It is of interest to compare these results with those obtained by the French National Railways, also on wooden sleepers :

before displacement	170 kg
with intermittent displacement, up to	410 »
with continuous displacement, more than	410 »

On the other hand, we find in *Die Bundesbahn* of October 1954 the following figures, again for a whole sleeper of wood :

in the running track	1 170 kg
in test track, beginning of movement	210 »
in test track, maximum value. .	525 »
basis of calculation	260 »
to	400 »
according to Corini, at the beginning of movement	400 kg

according to other German research workers . . . . . 660 »

There is an undeniable agreement between our value of 180 kg deduced from trials on running track, and the French and German figures of 170 kg and 210 kg, respectively.

In our opinion, not too much importance should be attached to direct trials on sections specially constructed for this purpose, for the following reasons :

(1) The ballast as a whole is more easily movable in a test track than in a track actually in operation, as the ballast is rarely stabilized to the same extent as it would normally be under the influence of the vibrations caused by passing trains.

(2) The stone material under the supporting surface of the sleeper has not yet « bitten » into the latter so that the friction coefficient remains relatively low.

(3) There is not the reciprocating motion which, in practice, in spite of the effect of the vibrations, leaves a slight gap around the sleepers which facilitates the subsequent movements every time.

It seems that, in practice, point 3 outweighs the two first points.

This means that we can write equation (11) as follows, for wooden sleepers spaced at 0.60 metre :

$$z = 0.03\ \Delta t^2 \qquad (20)$$

When the spacing is changed, the factor 0.03 varies at the same rate.

B. *Annual variations.*

Apart from several days during which readings were made all the time, records were also taken, over a period of several weeks, at 8 a.m. and 4 p.m. every day. In the absence of more complete data, the points thus obtained on the diagram have been joined by straight lines. Figure 7 shows a polygonal outline enveloping these points. It is obvious that, if there had been more frequent readings, certain points would have been found outside this envelope. Generally speaking, however, the discrepancies cannot be very great.

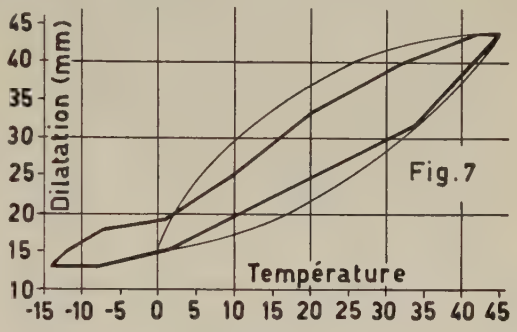


Fig. 7

Although the graph shows temperatures below 0° C, these have been disregarded. In practice, the ballast is solidified under such conditions, and it is no longer the sleepers which move in the ballast, but the rails which move in their fastenings. This phenomenon applies on lines with steam traction as the ballast on such lines is often fouled to a greater or lesser extent with ash particles which retain some water so that, during frost, the ballast stones are welded together by ice. It will also be seen from the graph that the contour line shows a different trend below 0° C. In contrast, these considerations do not apply to a line operated by electric or diesel traction where the ballast remains movable, even at periods of heavy frost. It is this assumption alone to which we have adhered, as it is apparently bound to

become the general case soon, and as it represents, in any case, the assumption most unfavourable for the calculations. In practice, the resistance of the fastenings, varying between 1 000 and 2 000 kg for each assembly, is always greater than the resistance of a half-sleeper in ballast assumed to be movable, and it is therefore the latter which will normally give way.

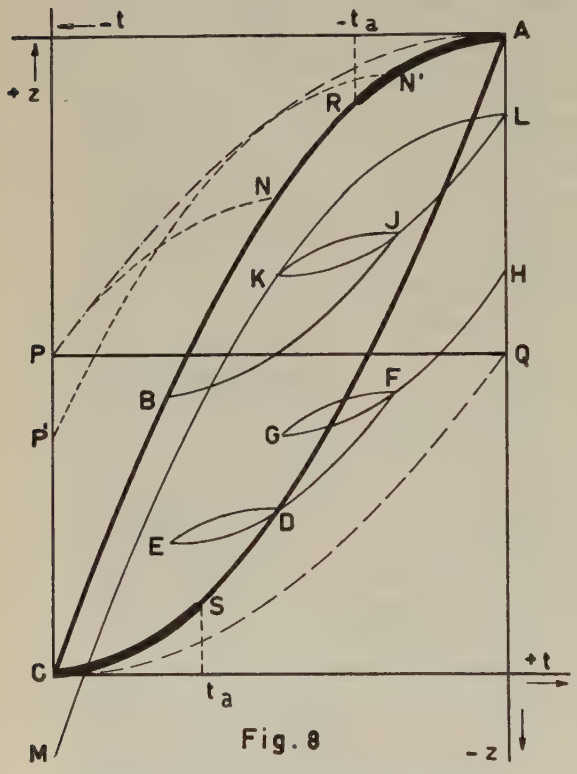


Fig. 8

We have tried to find in the curve enveloping the points over 0° C the shape of a twin parabola. This figure agrees reasonably well with the formula :

$$z = 0.015\,\Delta t^2 \quad (*) \qquad (21)$$

(*) Here too the coefficient varies according to the sleeper spacing.

The parameter of this parabola is equal to exactly half the value of that shown in equation (20) on the basis of the daily variations. We are inclined to look for the cause in the « law of the previous conditions » which is as capricious and elusive as the meteorological phenomena themselves. Even so, we may perhaps succeed in providing an explanation.

Figure 8 represents the left-hand side of figure 3, except that the system of coordinates has been turned by 90°. The characteristic curves have been inscribed in a rectangle of a width exactly corresponding to the range of the extreme annual temperatures, and of a height corresponding to the greatest variation in length to which one of the rail ends can be subjected according to formula (20). The origin of the axes is located at A for the descending branch and at C for the ascending branch.

We may, for instance, depart from point C which represents the lowest temperature imaginable, and assume that, as the temperature rises, point D has been reached. If this rise is followed by a temperature drop, the point on the graph will move to E, having described a parabolic arc similar to that over a section of equal length starting from A in the direction of B. If the temperature rises again, the point E on the graph moves along a parabolic arc, still of the same parameter, passing through D and ending say, at, F. From F, it may drop back to G, and then rise to H at the temperature assumed to be the maximum. Although we have used, all the time, parabolic arcs corresponding to equation (20), but longer or shorter sections according to the daily variations, we have

arrived point H : that is to say that the length variation of the rail is considerably smaller than it would have been, if we had introduced into the formula the full annual range of temperature fluctuation, in which case we would have arrived at point A of the graph.

If we apply the same reasoning to a departure from A, but choosing different lengths for the partial arcs, we would be able to let the point on the graph follow a trajectory marked successively by the points B, J, K and L (a point situated between A and H, yet corresponding to the same maximum temperature), or finally by M, which would mean a greater contraction (at least theoretically) than it would have been possible to predict from equation (20).

It follows that, in consequence of the temperature fluctuations, the point (t, z) may be situated not only at any point within the area ABCDA, but that it may even be situated outside its contour.

Let us further assume that, in consequence of a temperature drop, the point may have described the parabolic arc AN, and that the temperature remains for a moment at that level, with a slight *tendency* to rise, but without succeeding in completely reversing the interplay of forces. If this period is followed by a new temperature drop, the point will describe another parabola NP in the same direction, and again with the same parameter. An arc N′P′ might have been described in similar circumstances. This gives rise to a family of parasitic parabolas which have their vertices on the original parabola and possesses an envelope. A calculation shows that the envelope is another parabola having its vertex at A and a parameter equal to half the parameter of the original parabola as determined by equation (20), which was 0.03. We thus find again, by a totally different approach, the empirically established equation (21). Could this be regarded as a mere accident?

We find that this new parabola intersects the vertical through C at P, at the mid-point of the total amplitude, whilst the other branch, starting from C, reaches the vertical through A at Q, equally at the mid-point.

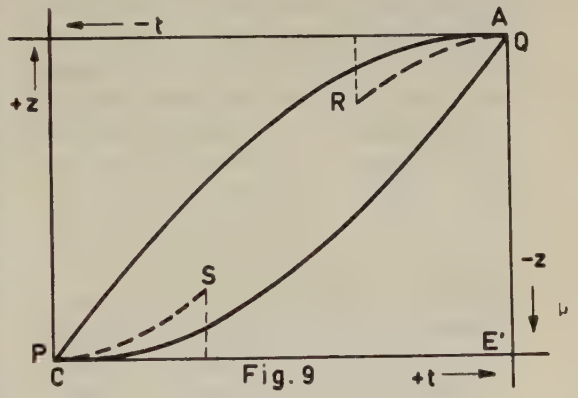


Fig. 9

One could imagine that it would be possible to construct, on this envelope parabola, a second family of parasitic curves with a second envelope of their own, and so forth, so that one would be able to sweep, with the point on the graph, the entire rectangle constructed over A and C. This is, however, not the case in practice. Nature seems to be content with the first envelope. Since P corresponds to the lowest temperature and Q to the highest temperature, it would seem logical, in order to reproduce the annual movements of the rails, to compress the figure in the vertical direction so that P coincides with C, and Q with A (fig. 9).

A new closed circuit (AQ) — (PC), of annual character, takes the place of the former ABCDA, of which only two sections, AR and CS (which correspond to no more than one-third, at most, of the total temperature range) remain available as images of the daily variations.

C. *Conclusions.*

If we could know, from direct observation, the true expansion values at the extreme temperatures, the laying of long rails would not pose the problem which we have here discussed in detail. But the extreme conditions are rarely experienced in Belgium. One is therefore compelled to confine the observations of the phenomena to a more limited range of temperatures, and to look for a law which permits extrapolation.

The preceding considerations can therefore be summed up as follows :

(1) The first rise or drop in temperature immediately after the laying of the rail causes each end of the rail to move, as determined from the transformed equation (8), over :

$$z = 0.06\ \Delta t^2; \qquad (*)$$

(2) The daily variations of the temperature cause movements in accordance with equation (20) :

$$z = 0.03\ \Delta t^2; \qquad (*)$$

(3) The annual variations of the temperature combine the preceding movements in a law expressed by equation (21):

$$z = 0.015\ \Delta t^2; \qquad (*)$$

(*) In each case the coefficient is valid for a sleeper spacing of 0.60 m and varies eventually in the same rate as the latter.

(4) The mean resistance of the ballast against the sliding of the sleepers amounts to *180 kg* per sleeper; as a whole, however, day after day, the ballast acts on the sleepers as if the passive resistance were *twice* as high, i.e. *360 kg*.

IV. New records.

Since the first trial section referred to above was established, several other sections with long welded rails have been laid on the Belgian Railways, measuring between 400 and 900 metres in length according to local circumstances, and totalling at present 45 kilometres. These rails are partly laid on wooden sleepers with clip-type baseplates, and partly on concrete sleepers with elastic fastenings.

On certain of these rail sections, it was possible to make observations similar to those made on the original trial section. Each time, these observations were carried out at the four joints limiting a pair of long rails. As these rails were followed by other rails of very great length, the variation in the gap at the point represented, in fact, the aggregate movement of *two* rail ends which are deemed to move in the ballast in an identical manner. Although the probability of these movements being equal is in fact small, one did at least obtain an average value every time, and the four joints could together be regarded as representative of eight movements.

In analysing the results in the way described above, we have tried to work out, in different cases, the value of the quotient $\frac{t_d^2}{z_d}$ for which the trial section had yielded the value 34 for daily movements and 17 for annual movements. The

average values obtained are tabulated below :

	Wooden sleepers	Concrete sleepers
Site No. 36 :		
Daily movement . .	95	99
Annual movement. .	69	62
Site No. 161 :		
Daily movement . .	40	66
Annual movement. .	40	55

It will be seen that the results are far from being in agreement with each other.

At Site 36, the two pairs of rails under observation were exactly side by side. The results seem to show that the resistance of concrete sleepers against displacement is the same as that of wooden sleepers. But the quotient is greater than on the earlier trial site, and its value for the annual movements is more than half of that for the daily movements. The first of these findings might be explained by the fact that the trains run over the section concerned at high speeds (100 to 120 km.p.h., or say 60 to 75 m.p.h.) so that, because of the greater violence of the vibrations, the ballast is better shaken down in the gaps between sleepers, thus increasing the resistance of the latter. The second finding, on the other hand, tends to annihilate the theory of the parasite parabolas, though still leaving scope for the idea of an appreciable difference between daily and annual movements.

As far as Site 161 is concerned, the observations made on wooden sleepers lead us more or less to the value already found on the trial section. But they show no difference between daily and annual variations for wooden sleepers, and little difference for concrete sleepers. It is relevant to point out that, at the time of the observations, the speed of the trains was greater on the section with concrete sleepers than on the section with wooden sleepers, viz. about 80 km.p.h. (50 m.p.h.) and 60 km.p.h. (37 m.p.h.) respectively, the latter speed being of the same order of magnitude as that on the trial section (50 km.p.h. = say, 30 m.p.h.).

By introducing into equation (19) the figures indicated above, we find that the resistance of a sleeper in the ballast can reach 530 kg instead of 180 kg as previously found. If the latter value was very small (though it was found to be confirmed by certain observations made abroad), the new value of 530 kg still remains within the order of magnitude mentioned by other research workers.

The rails which we are discussing have only experienced two winters so far, and one of these has been rather severe. Before the first summer, they have undergone a general relaxation of stresses which had, however, not any marked effect on the length variations. In contrast, on one occasion during the summer, they were exposed to a temperature of 50° C, which is only 5° C below that temperature which we regard as the highest possible temperature (measured at the rail) in our regions. There was no incident on that occasion.

It must be concluded from the foregoing that the specific resistance of the ballast depends on numerous factors which, up to now, it has not been possible to find out with certainty. The results of the various more recent records do not invalidate the theory developed earlier on. But they weaken, to a certain extent, the

assumption of the parasite parabolas, though this assumption still appears to be true up to a certain point.

V. Laying of rails of very great length.

We shall now seek to derive, from the foregoing, some directives concerning the maximum expansion gap and its aperture to be left *at the time of rail laying*. We must lay stress upon this condition since,

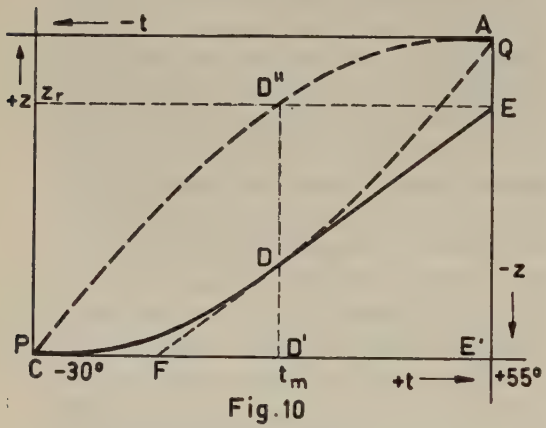


Fig. 10

once the rail has been laid, it is no longer possible to find any means of advance calculation of the gap, as will have been appreciated in the light of figure 8.

Let us first attempt to determine under what conditions a rail may be regarded as being of « unlimited length ». It might be possible to deduce these conditions from equation (12), adapted in the light of the developments discussed earlier on. But as these have finally led to formula (21), it is easier to start from the latter, with the aid of figure 10.

Let us see what happens in a rail of relatively short length, departing, for argument's sake, from the extreme minimum temperature represented by point (PC). As the temperature rises, the point on the graph begins to move along the parabola (PC) D (QA). But when it reaches, for instance, position D, corresponding to a temperature t_m, we assume that the « respiratory » movement of the rail has reached the centre M of the rail of a length L. From this moment onwards, the point on the graph follows a straight line DE which is tangential to the parabola at D and which represents the free expansion of the rail. Its inclination is $\frac{\alpha L}{2}$. Being a tangent, this inclination also represents the derivation of function (21), viz. $0.030\Delta t_m$. By making these two terms equal, we obtain (taking into account the units chosen) :

$$L = 5.2\ \Delta t_m \qquad (22)$$

It follows that, for a total temperature range of 85° C, a length of 442 metres must be regarded as representing the limit between « very long » and «relatively short » rails.

The actual opening of the joint at maximum temperature is found by calculating the ordinate E'E, which can be easily determined if it is remembered that F is midway between C and D'. One thus obtains, in millimetres :

$$z_r = E'E = 0.030\ \Delta t_m \cdot \left(85^\circ - \frac{\Delta t_m}{2}\right)$$

$$= 2.55\ \Delta t_m - 0.015\ \Delta t^2_m \qquad (23)$$

or $$z_r = 0.49\ L - 0.000{,}55\ L^2 \qquad (24)$$

In the first term of the second member one recognizes the effect of the free expansion on the half-length of the rail, and in the last term that of the impeded expansion. The parabola representative

for z_r, for a length L varying between zero and the maximum of 442 metres, follows the line (PC) D'' (QA), which is identical to the branch (PC) D (QA) though in inverse direction, and it will be clear that point E, which marks the maximum expansion for a half-rail of the length L, moves between the limit point E' and (QA).

The formulas quoted above also apply to very short rails which are supposed not to be restrained by their fishplates. However, in view of the small margin available in this case, it seems more accurate to start from formula (20) for the daily movements which would yield

$$L = 10.4\ \Delta t_m \qquad (22')$$

and

$$z_r = 0.49\ L - 0.000{,}28\ L^2 \qquad (24')$$

A brief calculation shows that it is only from a length of 30 metres upwards that the braking effect of the ballast has an influence on z exceeding a quarter of a millimetre, i.e. half-a-millimetre for the entire gap at the joint.

Reverting to rails of unlimited length, we find that, as the total temperature range encountered in Western Europe is estimated at 85° C (*), the greatest amplitude of the movement of one rail end amounts, according to equation (21), to

$$z_{max} = 0.015 \times 85^2 = 108 \text{ mm}$$

If the rail is laid in the spring or summer, and temperature rises must be expected, equation (21) determines the half-gap z_h to be provided at the joint, if Δt is taken to be the difference between 55° C and the temperature prevailing at the time when the rail is laid, i.e. $\Delta t = 55° - t_0$. In figure 11, the origin of the parabola is situated at U, at the temperature t_0 prevailing at the time, and the curve ends at Q at the maximum temperature.

But if one was led to suppose that, in the course of the first day to come, the temperature would rise from t'_0 to the maximum possible, it is necessary to adopt U' as the point of origin of the parabola so that the vertical projection of the arc U'Q corresponds to equation (8) where $(t_h - t_0)$ this time represents the difference between the maximum tem-

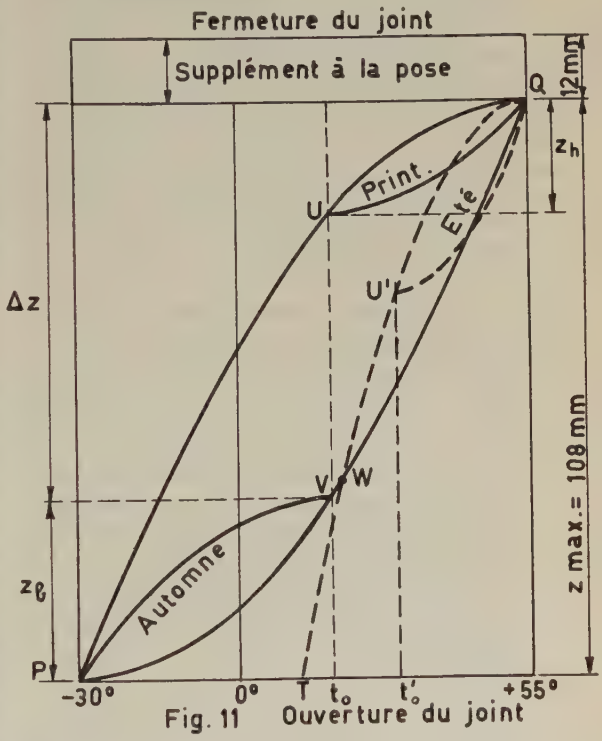


Fig. 11

Fermeture du joint = closing of joint. — Ouverture du joint = opening of joint. — Supplément à la pose = extra margin on laying the rail. — Automne = Autumn. — Print. (printemps) = Spring. — Eté = Summer.

(*) It is to be noted that the temperature of rails has a wider range than that of the surrounding air.

perature and that at the time when the rail is laid. The geometrical locus of the point U′ is a parabola of the same form, but of reversed direction, with its vertex at Q. It intersects the x-axis at its mid-point T, and intersects the branch PVQ at W, a point corresponding to three-fifths of the total abscissa, i.e. at a temperature of $(3/5 \times 85^{o}) - 30^{o} = +21^{o}$ C.

Now, in Belgium, the greatest amplitude of the daily variation of the temperature of the air is practically equal to 20° C.

It may be accepted that, during the night, the rail assumes the temperature of the air. During the day, however, the steel exposed to solar radiation can assume a temperature exceeding that of the air by as much as 15° C. The fluctuation in the rail temperature would then be 35° C. We have, in fact, measured an amplitude of 33° C. If it is thus assumed that the rail temperature can rise, during the day, to 55° C, the corresponding temperature at night might drop to 20° , a figure very close to that applying to point W. In practice, therefore, the locus for point U′ is confined to the parabola between Q and W.

Therefore, if there is reason to believe at the time when the rail is laid, that the highest possible temperature will be reached during the day, one will have to quadruple the gap determined from normal calculation.

If, on the other hand, a temperature drop is to be expected immediately after the rail has been laid, this reasoning is no longer valid. It is, in fact, practically impossible to experience, in the course of the work, a temperature of — 30° C.

If the rails are laid in the later part of the year (after 15th August) and the temperature shows a downwards trend, one will apply the same equation (21), introducing into it the difference between the temperature at the time and — 30°, i.e. $(t_0 + 30^{o})$. The origin of the parabola is at V, and its end at P. The contraction movement to be expected is z_b, and the half-gap at the joint $\Delta z = z_{max} - z_b$.

The margin to be provided by the expansion device is thus determined to be $2 \times 108 = 216$ mm, to which it is advisable to add a small extra margin, e.g. $2 \times 12 = 24$ mm, to make up for possible errors. One thus arrives at a total of *240 millimetres*.

Figure 4 has shown the possibility of peak stresses, absolute as well as relative, occurring in a rail. These peaks may also have other causes than the normal fluctuations of the ambient temperature, such as, for example, a temperature change occurring while the rails are laid, the heat introduced into the rail by the welding of a joint or by build-up welding, or an accidental local increase in the resistance of the ballast. We are of the opinion that these accumulations of stresses cannot subsist for a long time. They are bound to dwindle gradually owing to the actual fluctuations in the temperature and, especially, owing to the vibrations and other movements due to the passage of trains. It is, by the way, interesting to notice, when standing close to a very long rail, that the rail begins to « hum » when an approaching train is still some 200 metres away. On the other hand, it is also easily conceivable that a sudden heat wave can accentuate the peak stresses if, for any reason, certain constituent parts of that heterogeneous assembly known as the track refuse to follow accurately the

movement which they are supposed to carry out in theory. Such a phenomenon, however, should not, it is believed, last longer than a couple of hours.

VI. Comparisons.

It is rather interesting to see that the French and Belgian railways use welded rails up to a maximum length of about 800 metres (half-a-mile), ending in expansion joints which leave a margin of the order of 200 millimetres, whilst the German system and certain American companies use rails of much greater length, interrupted merely because of track layout considerations (insulated joints; points and crossings). On these railways, the ends of the long rails simply consist of ordinary fishplated joints, the only precaution being to multiply the anti-creep anchors in their vicinity. Other research workers have recommended the use of a very small gap of only 8 millimetres. Let us see how these different views can be explained on the basis of our formulas.

In Germany, it is the practice to give the joint a zero gap at a temperature just under + 30°, say 28° C. Moreover, account is taken of the freezing of the ballast at a temperature below — 10° C, as well as of the gliding resistance offered by the fishplates, estimated at 5 tons and corresponding to a temperature variation of

$$\frac{5\,000 \text{ kg}}{6\,000 \text{ mm}^2 \times 0.25 \text{ kg/mm}^2} = 3°.$$

If, after the rail has been laid, the temperature drops, the joint thus begins to open at 25° C.

Our formula, if applied to the German stipulations, thus yields, for a single string of rails,

$$z_1 = 0.03 \times \frac{0{,}655}{0{,}60} \times \frac{90}{330} \times \Delta t^2 = 0.009\ \Delta t^2$$

valid between + 25° C and — 10° C. As the ballast is supposed to be solidified at a temperature lower than — 10° C the resistance then encountered by the sleepers becomes much greater than the resistance encountered by the rail at the fastenings. For a half-sleeper, this resistance, normally, 90 kg, rises to about 1 000 kg :

$$z_2 = 0.03 \times \frac{0{,}655}{0{,}60} \times \frac{90}{1\,000} \times \Delta t^2 = 0.003\ \Delta t^2$$

valid between — 10° and — 30° C.

By introducing the actual values of Δt, i.e. 35° and 20° respectively, we obtain

$$z_{max} = z_1 + z_2 = 11.0 + 1.2 = 12.2 \text{ mm.}$$

It is usual in Germany not to join two long rails with each other : they always end in at least one 30 metres rail with ordinary joints which move according to the usual rules. Let us apply our earlier calculation to them. Formula (12) yields :

$$t_m - t_0 = \frac{pL}{2SE\alpha} = 0.01.p$$

(p in kg/m for one string of rails and a sleeper spacing of 0.60 metre).

As long as the ballast is loose, its resistance is overcome by a temperature differential (using the German values) of

$$t_m - t_0 = 0.01 \times \frac{330 \text{ kg/m}}{0{,}655 \text{ m}} = 5°.$$

The corresponding movement of the end of the rail amounts, according to equation (13), to :

$$z'_m = \frac{pL^2}{8SE} = 0.000{,}89.p;$$

Expansion joint used by the Belgian National Railways Company.

Introducing the numerical values, one obtains :

$$z'_m = 0.000,89 \times \frac{330 \text{ kg/m}}{0.655 \text{ m}} = 0.4 \text{ mm.}$$

After that there is a period of free expansion corresponding to :

$$z'_l = 15\text{m} \times 0.000,011,52 \times 30^\circ = 5.2\text{mm.}$$

For frozen ballast (at a temperature below — 10° C), formula (12) yields :

$$t_m - t_0 = 0.01 \times \frac{1\,000 \text{ kg/m}}{0.655 \text{ m}} = 15^\circ$$

and the corresponding contraction is :

$$z''_m = 0.000,89 \times \frac{1\,000 \text{ kg/m}}{0.655 \text{ m}} = 1.4 \text{ mm.}$$

Finally, there is a free contraction between — 25° and — 30° :

$$z''_l = 15 \text{ m} \times 0.000,011,52 \times 5^\circ = 0.9 \text{ mm.}$$

Altogether, each rail end will carry out a movement of

$$z'_{max} = z'_m + z'_l + z''_m + z''_l$$
$$= 0.4 + 5.2 + 1.4 + 0.9 = 7.9 \text{ mm.}$$

The joint as a whole can therefore have a maximum gap of

$$z_{max} + z'_{max} = 12.2 + 7.9 = 20.1 \text{ mm}$$

which is very nearly the figure prescribed by the German regulations (19 mm).

But the administration of the German Federal Railways also admits that this theory reaches the limits of the material possibilities. We read, in fact, in a report on this question : « A frictionless expan- » sion joint, though it may, because of its » large margin, exercize an unfavourable » influence on the stability of the sleepers » in the ballast, will nevertheless become » indispensable in areas with heavy tem- » perature fluctuations but no frost, as » well as in other cases where the ballast » offers but a light resistance against dis- » placement ». In our opinion, the lines operated with electric or diesel traction are among those not affected by frost, because of the absence of ash particles capable of retaining water in the track.

Turning to the theory which proclaims that a maximum gap of 8 millimetres should be sufficient, it is relevant to point out that the author of this theory admits the closing of the joint at a temperature of + 15° C, whilst regarding a low temperature of — 20° C as normal, and one of — 30° C as fairly frequent. Let us assume a mean value of — 25° C. Formula (20), if applied to this temperature differential, doubling the result so as to obtain a value for the whole joint, yields 96 millimetres. The mentioned formula is based on the assumption of a resistance of 150 kg/m, whilst with the method in discussion, the resistance is estimated at 1 800 kg/m. We thus obtain, through reduction, a possible maximum gap of

$$96 \times \frac{150}{1\,800} = 8 \text{ mm,}$$

which is the figure put forward.

We might be criticized for having chosen, to suit our purpose, equation (20) expressing the daily variations, and not equation (21) expressing the annual variations though we have tried to justify this formula at length in the foregoing discussion. We do, however, believe ourselves justified in assuming that, with the very small displacements occurring here,

which are the consequence of a very powerful braking effect of the sleepers in the ballast ($p = 1\,800$ instead of 150 kg/m), there is no need of making a distinction between daily movements and annual movements. We have, incidentally, acted in the same way in connection with formula (24').

To sum up, we believe that as steam traction (being the cause of ash particles on the track) is gradually abandoned, the railway administrations which possess long welded rails with ordinary joints will have to decide to make use of expansion devices. The actual maximum length of the rails will depend on other considerations mainly of a practical kind, such as the possible need for a subsequent adjustment of the stresses after the rail has been laid, or the occasional repair of damage. As regards the very small joint of 8 mm, we are of the opinion that this arrangement is not suitable for Belgium and adjacent countries.

[625 .214]

Roller bearing axleboxes in railway vehicles,

by F. LAMBRECHTS,

Civil Engineer U.I.Lv.

I. — INTRODUCTION

The increase in axle loads and running speeds of railway vehicles has made it necessary to carry out investigations in order to improve the traditional axleboxes.

Different methods have been tried such as the substitution of the lubrication of the plain bearing with an oil pad or « Perfect packing » operating at the lower part of the journal by constructions giving a more important and rational lubrication on the upper part of the journal.

On the other hand, axleboxes of an entirely different design, the roller bearing axleboxes, have given an interesting solution to the problem of high speed and increased axle load.

The use of the roller bearing axleboxes in railway vehicles has now developed to such an extent that it would appear opportune to give a short historical account and to summarise the results obtained with these axleboxes, which are used by railways all over the world.

A well-known Swedish bearing manufacturer fitted ball bearing axleboxes to railway vehicles as long ago as 1911, and about ten years later designed the spherical roller bearing, which has since become the Company's most important railway axlebox bearing.

The introduction of this bearing has had a marked influence on the use of roller bearing axleboxes in railway vehicles as shown by the graph in figure 1, which clearly indicates the present tendency; the figure of 1 000 000 roller bearing axleboxes, which was reached in 1955, covers axleboxes in use throughout the world and fitted to all types of railway vehicles

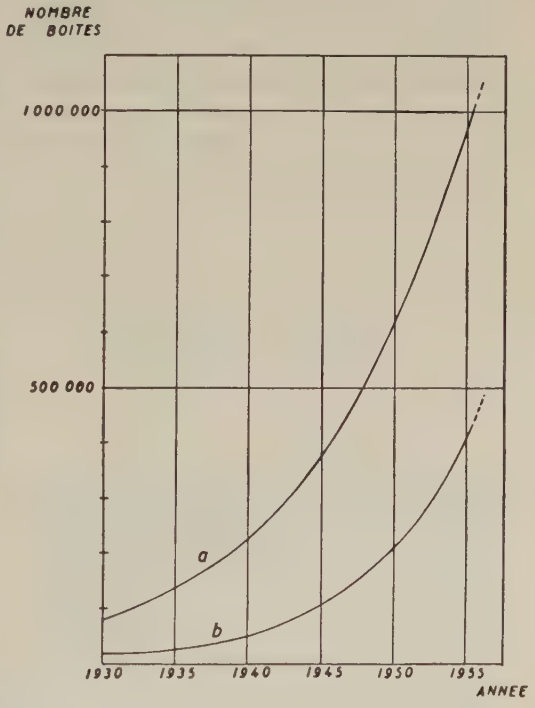


Fig. 1. — Number of SKF axleboxes in use in the world.

Curve *a* : total number of SKF axleboxes.
Curve *b* : number of SKF goods wagon axleboxes.

ranging from high-speed electric locomotives to passenger coaches, multiple unit stock, rail-cars, all types of goods wagons, etc.

It may be asked how this remarkable result has been achieved despite the fact that the initial cost of roller bearing axleboxes is usually greater than plain bearing axleboxes and the necessity to overcome a tradition that has persisted for almost a century.

The answer is that roller bearing axleboxes have more than come up to all that was expected of them. On the basis of over 30 years' experience and cost calculations from many railway administrations of the world, it may now be definitely concluded that although roller bearing axleboxes usually cost more than plain bearing axleboxes, they are actually more economical because their great advantages offset their higher initial cost.

II. — THE ADVANTAGES OF ROLLER BEARING AXLEBOXES

a) *Reliability.*

When one speaks about roller bearing axleboxes the first thought that comes to mind is the saving in tractive effort. This saving is considerable, as will be shown later, and cannot be disregarded, but the most important advantage of roller bearing axleboxes is their exceptional reliability.

Roller bearing axleboxes do not run hot, which is of particular importance to railways. The statistics of railway administrations show that certain vehicles incur particularly high expenses due to hot boxes. Moreover, these expenses tend to increase from day to day as the result of increased speeds. Under these conditions old vehicles cause an increasing amount of trouble on the line and in depots because of hot boxes.

With roller bearing axleboxes, however, trains can attain their maximum permissible speeds without the risk of hot boxes even in cases where loads are exceeded. Consequently, no trouble or expense is caused by the following :

1) interruptions to traffic;
2) transport of the damaged vehicles to the workshops (which requires the use of a locomotive);
3) reloading;
4) possible compensation;
5) repair of the damaged axle journals and axlebox (a re-turned axle journal has a reduced carrying capacity);
6) possible repair of the vehicle, or sometimes a number of vehicles and track.

When railway vehicles are equipped with roller bearing axleboxes there is no longer any risk of derailments and other troubles caused by hot boxes, and greater reliability and better utilization of the available vehicles are obtained.

Another important advantage offered to railways is that service is improved as the result of roller bearing axleboxes permitting higher speeds.

In cases of necessity, a vehicle may be loaded with the maximum load without having to consider what type of train it is to run in. With plain bearing axleboxes it is sometimes necessary to limit the speed in the case of very heavy loads. This is not the case when vehicles are

fitted with roller bearing axleboxes. Wagons may be included in express trains or ordinary goods trains.

b) *Reduction of tractive effort.*

The bearings in roller bearing axleboxes have a very low coefficient of friction. The low starting resistance of a train equipped with roller bearing axleboxes compared with the starting resistance of the same train equipped with plain bearing axleboxes is particularly apparent. Measurements show that the starting resistance is often reduced by about 85 %. The tractive effort during running is, of course, not reduced to the same extent because the friction of the bearings has no effect on the effort required to overcome gravity and air resistance, and the saving obtained is in inverse ratio to the speed.

Numerous tests have been made with steam and electric locomotives, and the results have always shown a saving in tractive effort of several per cent, which has amounted to as much as 15 % in some cases. Figure 2 shows the final results of a number of tests; the abscissa shows the speed and the ordinate shows the saving in tractive effort as a percentage. It will be seen that at a speed of 120 km/h (74 m.p.h.) the saving amounts to about 5 %. Even this figure is sufficiently high to justify the wide-scale use of roller bearing axleboxes.

In the case of normal speeds and gradients, the tractive effort is reduced by an average of about 10 %, and there is therefore a considerable reduction in the consumption of fuel or electric power.

Expressed in absolute figures the reduction in tractive effort remains constant at 0.5 to 1 kg per metric ton hauled, independent of speed and gradient. Roller bearing axleboxes therefore make possible more rapid acceleration of the trains and shorter running times, especially on suburban lines.

As starting is easier there is better utilization of the tractive effort of the locomotive; the starting resistance is of particular importance in the case of steam locomotives. The weights of trains and

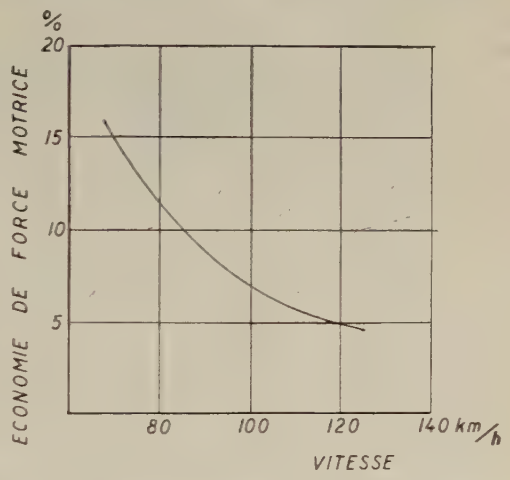


Fig. 2. — Graph showing tractive effort saving. Vitesse = speed. — Economie de force motrice = saving of tractive effort.

the number of vehicles hauled per train can be increased, the extent of this increase depending of course on the ruling gradient. In the case of unfavourable ruling gradient, with steep inclines, it has been noted that a plain bearing equipped train hauling 40 vehicles can be compared with a 44-vehicle train equipped with roller bearings. With less severe gradients it has been possible to couple 15 extra vehicles to a 40-vehicle train.

As each locomotive is capable of hauling a heavier load, this results in a reduction

of locomotive mileage for a given hauled tonnage. The cost of wages for locomotive personnel is reduced, as also locomotive maintenance costs. If the maintenance costs are estimated as being approximately proportionate to locomotive mileage, a 10 % reduction in this figure represents a 10 % saving in maintenance costs.

The resistance of roller bearing axleboxes during starting and running is independent of temperature conditions, which is a factor of great importance in winter.

The saving in tractive effort is, of course, most apparent in the case of a railway company whose vehicles are equipped throughout with roller bearing axleboxes. This saving is, however, no less real on railways where only new vehicles are equipped with roller bearing axleboxes whilst older-type vehicles are still equipped with plain bearings; the extent of the saving depends on the percentage of vehicles equipped with roller bearings.

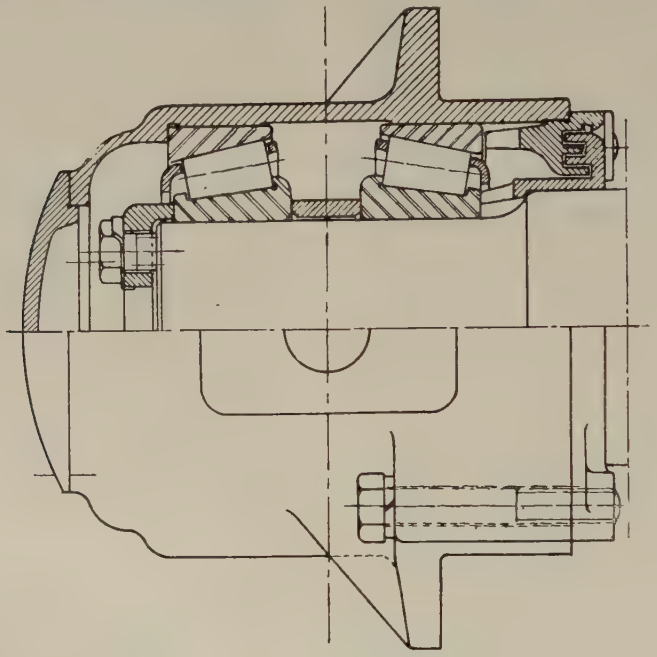


Fig. 3. — Taper roller bearing axlebox.

c) *Reduced maintenance costs. No inspection.*

In addition to exceptional reliability and the considerable reduction in tractive effort, railways are offered further important advantages. There are no expenses for line inspection and maintenance and there is a considerable reduction in workshop expenses.

Roller bearing axleboxes are lubricated with special high-quality bearing grease, supplied by the large firms which specialise in the manufacture of lubricants, so that

there is no risk of oil leakage. This is a particularly valuable feature in the case of coal and ore trucks which are unloaded on wagon tipplers.

Usually the bearings only require to be lubricated during periodic overhauls of rolling stock and locomotives.

A rail vehicle equipped with roller bearings does not need to be inspected during service — there is no need to check the temperature of the boxes. Plain bearing axleboxes, on the other hand, have to be inspected regularly at stops. Everyone acquainted with railways knows what this means : there is a saving of labour and there is no irritating delays, which results in improved service and a rational utilization of the available vehicles.

Apart from these reductions in working costs, the use of roller bearings also results in reduced general overhaul costs.

The roller bearings only need be dismounted from the axle journals in exceptional cases.

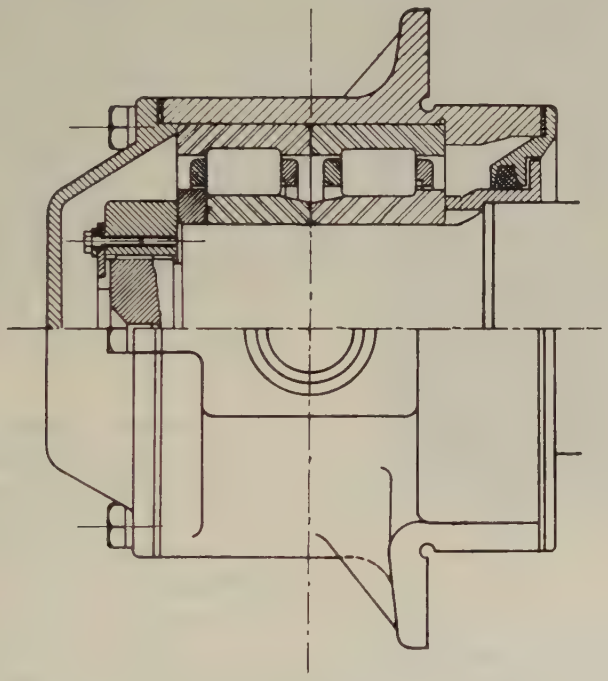


Fig. 4. — Cylindrical roller bearing axlebox.

The outer rings of spherical roller bearings can easily be swivelled for inspection of the rollers, cages and tracks, without having to dismount the bearings.

There are no bearing brasses requiring machining or relining, and it is not necessary to re-turn axle journals. The surfaces of the axle journals are not subjected to friction, do not wear, and

therefore retain their carrying capacity. In the case of plain bearing axleboxes the axle journals have to be serviced from time to time, and their diameter is therefore successively reduced.

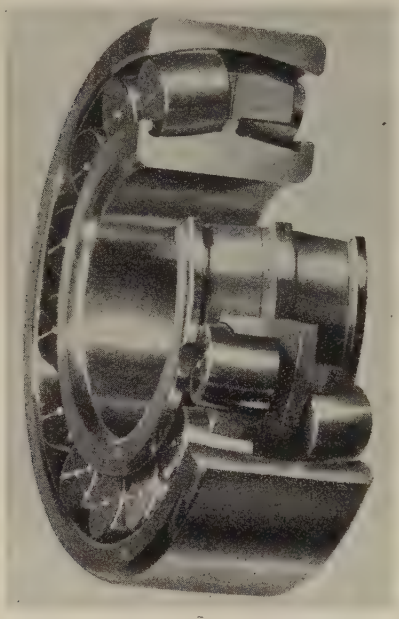


Fig. 5. — Spherical roller bearing.

In contrast to plain bearing axleboxes, oil pads, sealing discs or other components, which often need replacing, are not fitted in roller bearing axleboxes.

The amount of work connected with lubrication is reduced considerably, with a consequent reduction of lubricant and labour. It is now possible, for instance, for a wagon to remain in service for three or four years without inspecting the bearings, and with the high-quality greases now available, it may be possible to increase the intervals between overhauls still further.

The advantages of roller bearing axleboxes :

— absolute reliability,

— lower starting resistance and reduced tractive effort,

— no inspection — extremely low maintenance costs and the fact that railways require more modern equipment to maintain their place in the face of competition with other means of transport has made roller bearing axleboxes a factor of prime importance.

III. — DESIGN

There are various roller bearing axlebox designs, axleboxes with spherical roller bearings (fig. 7 to 11), axleboxes with taper roller bearings (fig. 3) and axleboxes with cylindrical roller bearings (fig. 4).

Axleboxes with spherical roller bearings will be dealt with in detail as they offer certain special advantages and are the most widely used.

The spherical roller bearing was specially designed in Sweden for use in axleboxes, and, compared with other types of bearing, it has been found particularly suitable for railway service because of its high radial and thrust carrying capacity and the fact that it is practically insensitive to shock loads. Moreover, the bearing is a self-contained unit so that there is no risk of mixing parts from different bearings.

A bearing of this type has two rows of rollers and a sphered track in the outer ring (fig. 5).

It is therefore self-aligning, and any out-of-parallel between the axle journal

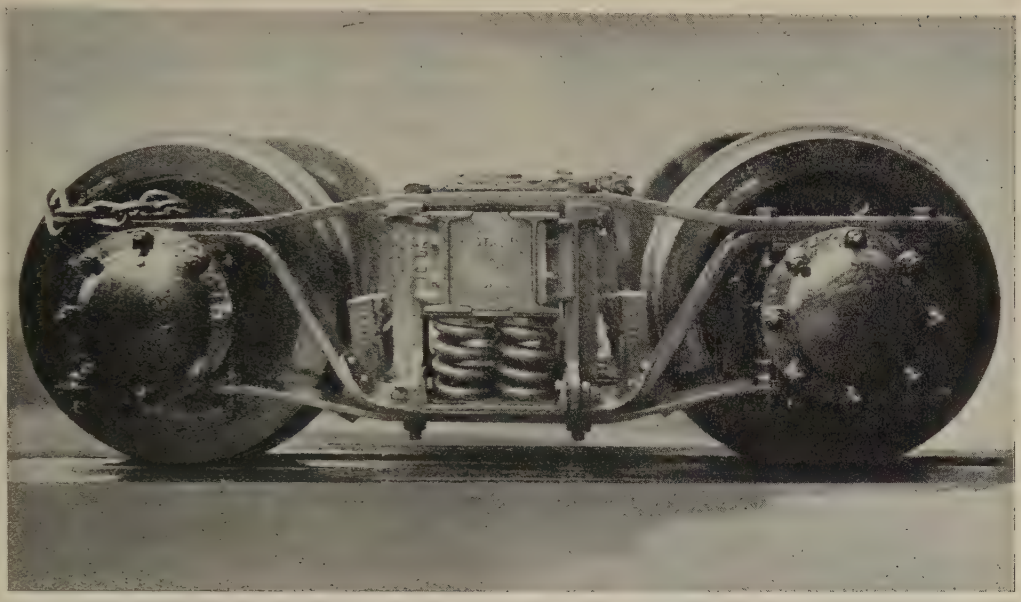


Fig. 6. — *Diamond* bogie fitted with axlebox of type shown in figure 7.

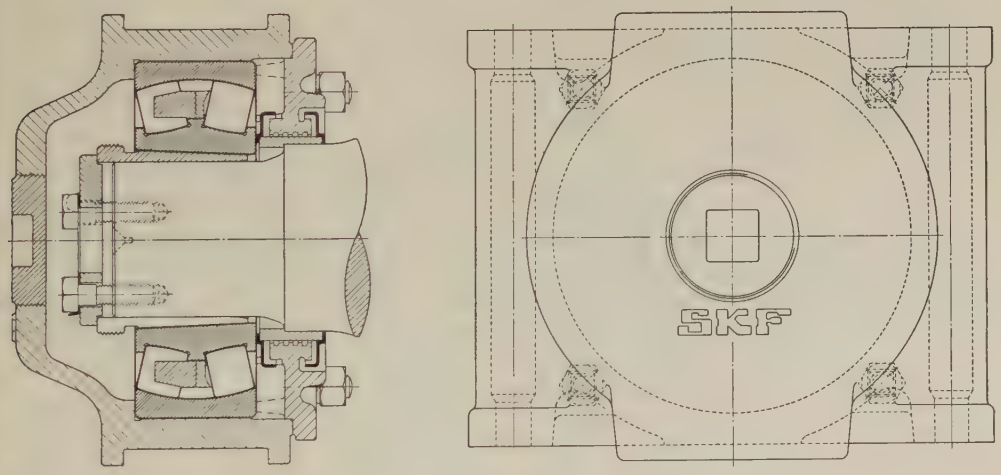


Fig. 7. — Axlebox for *Diamond* bogie.

and the box does not have any influence on its carrying capacity. This is of particular importance in single bearing axleboxes.

Axleboxes with spherical roller bearings may be divided into two categories : axleboxes with one bearing and axleboxes with two bearings. In the case of single-bearing axleboxes, a heavier series bearing with higher carrying capacity is, of course,

selected than in the case of twin-bearing axleboxes, in order to obtain the required life.

Single-bearing axleboxes should be selected wherever technically possible, i.e. in cases where the box suspension or lateral guidance prevents it from tilting.

1) With a single-bearing axlebox, there is no tendency for it to « corner » and no forces are set up when an axle is misaligned when, for instance, passing over rails joints.

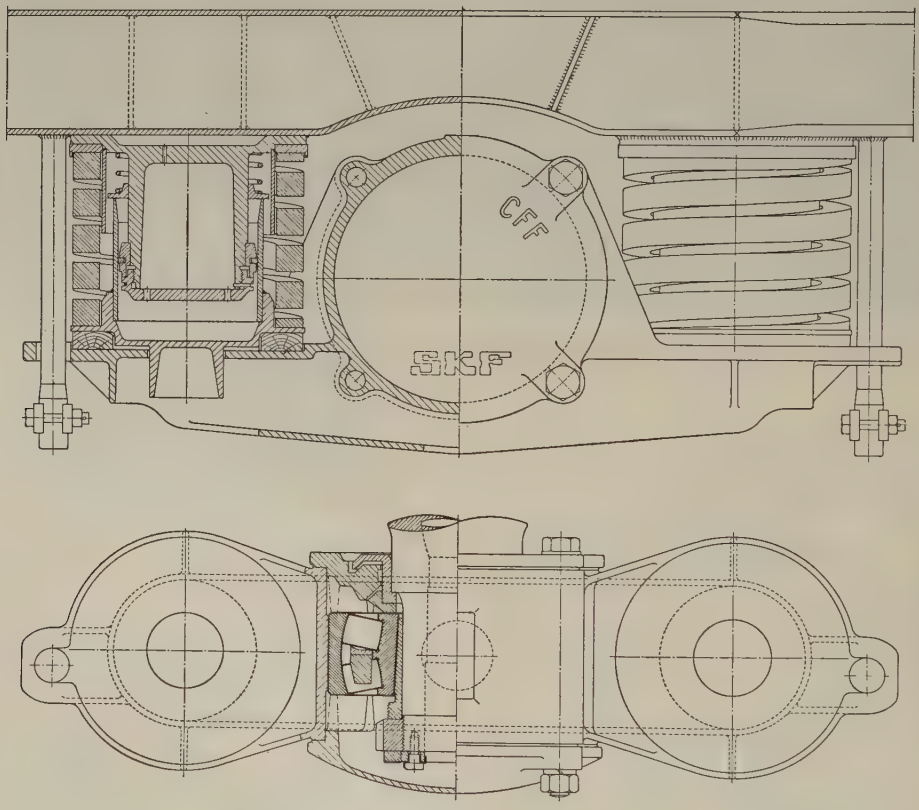


Fig. 8. — Axlebox for *Schlieren* bogie.

In single-bearing axleboxes all the advantages of the self-aligning ability of the spherical roller bearing can be utilized to the full, which means that the bearing outer ring may safely align itself obliquely in relation to the inner ring. This self-aligning feature means that :

In the case of a Diamond bogie, for example (figs. 6 and 7), the axleboxes are bolted to the side frames and therefore cannot tilt. A bearing scheme with one spherical roller bearing is no doubt the

best solution in this instance. A certain amount of flexibility can thus be obtained between the axles and the bogie frame, any deformation, whether temporary or permanent, having no detrimental effect on self-aligning bearings. The bogie will run more smoothly and it will hold the line better.

The self-aligning feature of axleboxes fitted with one spherical roller bearing has been found of great advantage in certain types of modern bogies for passenger coaches and locomotives. Examples are the Schlieren and Winterthur bogies in which the axles are guided without any play by four cylindrical guide posts, and whose excellent features are well known. The carrying springs rest on two brackets fittted on either side of the box below the centre-line of the axle. The load automatically keeps the box vertical (fig. 8).

The same applies in cases where the box is fitted with an underslung spring or equalizing beam (fig. 9).

2) The axlebox cannot move sluggishly or wedge in the guides — since there is no tendency for it to corner.

It is therefore possible to use flat liners and utilize their whole length to take the tranverse forces, which, of course, results in reduced wear of the liners and cylindrical guide posts.

3) Mounting is facilitated because, as in the case of the Schlieren bogie (fig. 8), after the two boxes have been fitted the axle set has to be fitted on to the four guide posts which are connected to the bogie frame. Axleboxes with one spherical roller bearing can be swivelled by pressing lightly with the hand during mounting, which simplifies the procedure.

The required stability for the use of single-bearing axleboxes obviously cannot be obtained in all railway vehicles.

In the case of four-wheel goods wagons for instance, the load is transmitted to the box by a leaf spring fitted on top of the box, and there is a considerable amount of clearance in the guides. In this application a single-bearing axlebox would tilt and retain an incorrect position. Plankless bogies are another example : the side frames of this type of bogie are not connected by a spring plank to make them rigid.

Twin-bearing axleboxes such as those shown in figs. 10 and 11 are used in all those cases.

Although twin-bearing axleboxes are not self-aligning, it is interesting to equip them with spherical roller bearings.

Even if the body is deformed, the load is always distributed evenly on the four rows of rollers because the outer ring track is spherical. This even distribution is of advantage to the life of the bearings, since if one row of rollers is more heavily loaded than the other rows, this row would fatigue earlier.

Axlebox bearings should always be mounted with a press fit on the axle journal. The question is whether to select a bearing with taper bore mounted on a taper sleeve (with the same taper as the bore), the drive-up of the sleeve in the inner ring giving the required fit, or a bearing with cylindrical bore mounted with a tight press fit direct on the journal.

The following should be considered when selecting the method to be used.

With the sleeve arrangement (fig. 10), mounting and dismounting are simple. When mounting, the sleeve is driven in

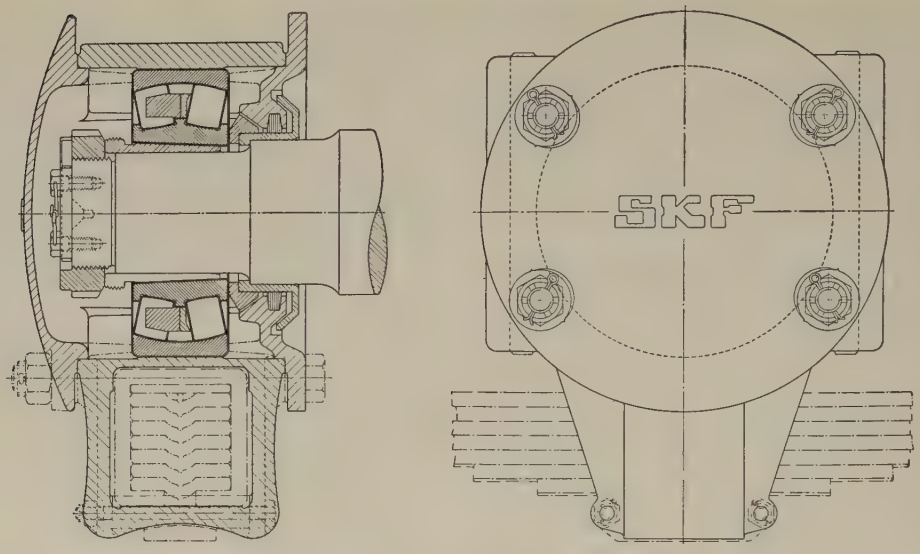


Fig. 9. — Axlebox with underslung carrying spring.

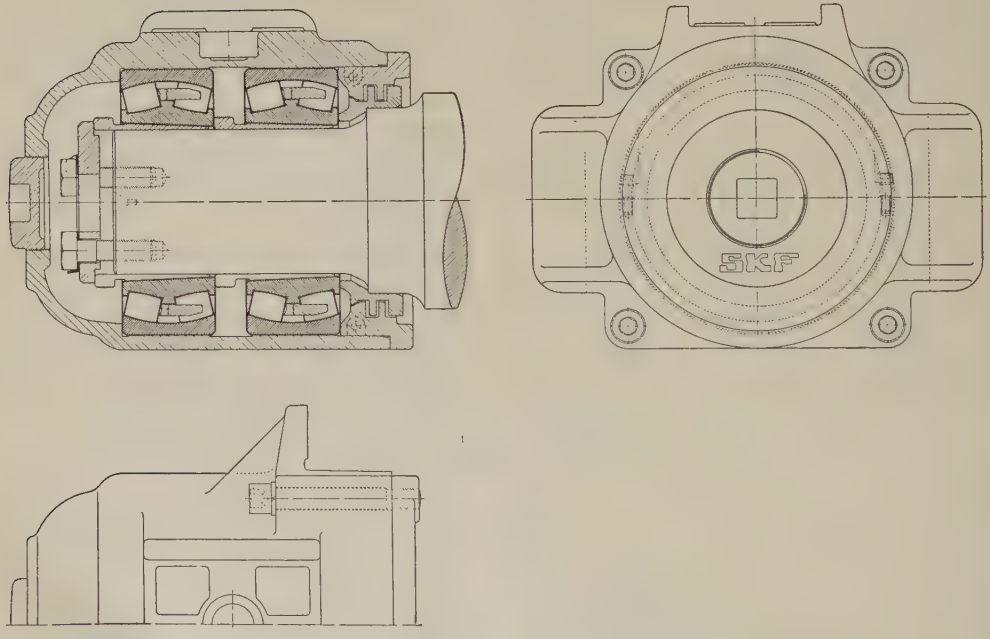


Fig. 10. — Axlebox with two bearings mounted on withdrawal sleeves.

until the required fit is obtained, this fit being measured by the reduction in the bearing internal clearance; when dismounting, a nut is screwed on the threaded end of the sleeve and the sleeve withdrawn from the bearing. Whilst the use of the sleeve means a certain increase in price, it should be remembered that the axle are determined solely by the tolerances of the bearing and journal.

Both methods of mounting are widely used throughout the world, and both offer complete reliability.

From the foregoing the reader will be able to decide which method is most suitable for a particular case; the require-

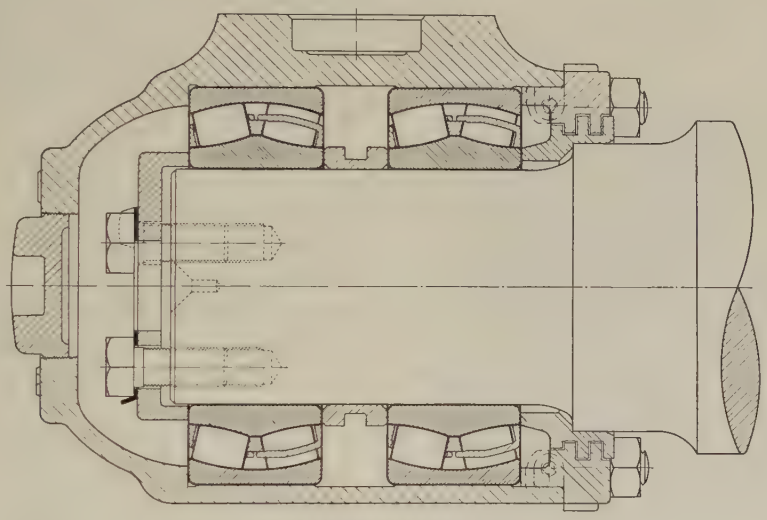


Fig. 11. — Axlebox with two bearings mounted direct on axle journal.

is cheaper because a wider tolerance is permissible for the journal. Slight differences in diameter are compensated by the taper sleeve.

Mounting direct on the axle journal (fig. 11) may be effected either with a press or by first heating the bearing in an oil bath to expand the inner ring. It is necessary to provide a press for dismounting.

In the case of spherical roller bearings, no adjustment is necessary with direct mounting because the fit of the inner ring on the journal and the bearing clearance

ments and wishes of the vehicle user must, of course, be taken into account.

IV. — LIFE

If a bearing is exposed to moisture or dirt, it may become unfit for service because of rust or wear. These causes of reduced life are eliminated by the use of a suitable axlebox design with effective sealing, lubrication with a high-quality axlebox grease and correct maintenance.

The only cause of reduced life that cannot be eliminated is fatigue of the material. During rotation the rollers and

tracks are subjected to repeated stresses as the rollers pass through the loaded zone, and fatigue finally results in flaked rollers or tracks.

An advantage of roller bearing axleboxes, however, is that even if flaking occurs there is no risk of a hot box. It is sufficient to change the bearing during the next overhaul.

Roller bearing axleboxes with underdimensioned bearings, would however, lose much of their value as the result of frequent dismounting and bearing replacements. It is therefore obvious that railways require bearings of adequate carrying capacity and life, thus reducing the number of bearing replacements during overhauls.

Life is therefore a question of vital importance when selecting roller bearings for axleboxes, and everyone concerned with the design of railways vehicles should be acquainted with the following points.

Experience has shown that individual bearings of the same design and material have different lives even when working under identical conditions. The calculation of bearing size therefore requires a clear definition of the term « life ».

In order that the requirements as regards reliability and low cost may be suitably balanced, calculations of the carrying capacity may be based on the life attained or exceeded by 90 % of all the bearings. If, for example, bearings are dimensioned for a calculated life of 20 years, 90 % of them will attain or exceed this life.

On this basis, a bearing may be characterized by its « dynamic carrying capacity », i.e. the constant load under which the bearing will attain a « life » of one million revolutions.

This carrying capacity applies to certain definite working conditions : during the operational period of the bearing the load is assumed to be constant and purely radial.

The actual bearing load must be converted to a hypothetical load fulfilling the conditions applying to the dynamic carrying capacity and which, as far as the life is concerned, has the same influence on the bearing as the loads actually imposed. This hypothetical load is called the « equivalent bearing load ».

The conversion of actual loads to equivalent loads can be carried out simply with the aid of formulae given in special catalogues.

These rather dry definitions help us to reach the core of the problem more easily.

According to the above it is not sufficient to select bearings that could be used for only a few hundred thousand kilometres, and from what is said later it can easily be seen that it is false economy to try to

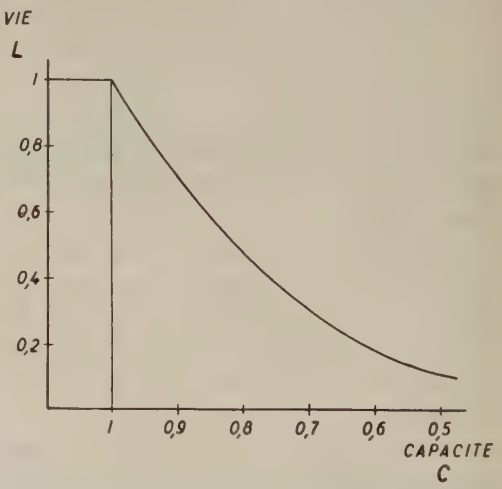


Fig. 12. — Graph showing the relationship between life and carrying capacity for a given load.

reduce the cost by selecting underdimensioned bearings. The final result would be a cost per kilometre for the axleboxes many times in excess of what it would have been if the bearings had been calculated correctly.

For a given load the relationship between the life of a roller bearing and its carrying capacity is based on the following formula, which has been arrived at empirically and has been confirmed by theory and practical tests :

$$L = \left(\frac{C}{P}\right)^{10/3}$$

where L = life in millions of revolutions,

C = dynamic carrying capacity of the bearing, kg,

P = equivalent load per bearing, kg,

all of which are according to the definitions given in the foregoing.

For a given load the graph in figure 12 shows the variation in the life as a function of the carrying capacity in accordance with the formula given above.

Capacity	Life
1.0	1.0
0.9	0.71
0.8	0.48
0.7	0.31
0.6	0.18
0.5	0.10

Fig. 13.

It can be seen immediately that a slight reduction in the carrying capacity results in a considerable reduction in the life. The table in figure 13 gives the numerical values.

In other words, it is very important to determine the actual loads on the axlebox and bearing during operation. A calculation, which does not take into account the additional dynamic radial forces

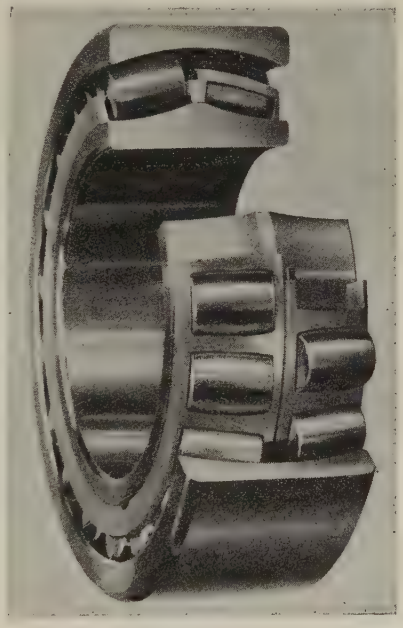


Fig. 14. — The SKF « C » -type spherical roller bearing.

occurring, for example, when a vehicle passes over rail joints, or the thrust forces to which the axlebox is subjected, would lead to quite incorrect results.

A calculation made according to the formula given above, but based on underestimated loads and therefore an

equivalent load that is too low, might give a satisfactory C/P value, but the effect on the life due to the mistake made in estimating the equivalent load P is proportional to the power 10/3. The actual life would therefore be reduced in the proportions shown in figures 12 and 13.

Comparison of the carrying capacity of the bearings in axleboxes of different type is therefore a matter of particular importance to railways.

This question has been taken up by the Union Internationale des Chemins de Fer (U.I.C.), and it is hoped that in collaboration with I.S.O., it will be possible to make a formula available which can be used by railway administrations for comparing the carrying capacity of different bearings.

In the meantime a proposal has been made to the railway administrations, to enable them to compare the capacities of the different bearings offered to them.

The actual cost of an axlebox is its cost per kilometre, and if the carrying capacity of the bearings is known it is easy to compare two types of box with the aid of the graph in figure 12.

(SNCB photo).

Fig. 15. — Diesel-electric locomotive, type 201, total weight 87 tons.

V. — A NEW TYPE OF ROLLER BEARING FOR AXLEBOXES

The original spherical roller bearing was designed by SKF over 30 years ago (fig. 5).

This spherical roller bearing, called the C-type, is particularly suitable for roller bearing axleboxes in view of the present tendency to increase axle loads and running speeds, with the consequent increase in bearing loads and annual mileages. The

(SNCB photo).

Fig. 16. — Electric locomotive, type 123, total weight 92 tons.

In 1947 SKF produced a spherical roller bearing of new design, which has a carrying capacity approximately 40 % greater than the older-type bearing, its life being 2 ½ to 3 times greater (fig. 14).

Roller bearings of this new type have now been in use for 6 years under the most arduous working conditions, especially in rolling mills and railway vehicles, and particularly satisfactory results have been obtained.

new C-type bearing meets these requirements, with moderate dimensions and price.

The increased carrying capacity of the bearing is made possible by the fact that there are no fixed flanges on the inner ring. A loose ring of comparatively narrow and high section, together with the cage, ensures accurate guidance of the rollers.

The contact length between the rollers and the tracks is much greater than in bearings of older type as the result of the increased length of the rollers and, in particular, the absence of grinding reliefs on the inner ring.

The new design of cage makes possible the manufacture of bearings in wider series, which is of value in cases where radial space is limited.

Tens of thousands of axleboxes with the new bearing are now in service on railways throughout the world, including the S.N.C.B. Figures 15 and 16 show S.N.C.B. locomotives equipped with axleboxes fitted with C-type bearings.

VI. — SUMMARY

The use of roller bearing axleboxes for railway vehicles is rapidly increasing. More and more railway administrations are systematically equipping their new locomotives and rolling stock with roller bearing axleboxes, and roller bearing axleboxes are being used extensively in the modernization of vehicles originally equipped with plain bearings.

This is primarily due to the quality of the bearings and to the close technical co-operation between the engineers responsible for the design of the most suitable axleboxes for a particular application, the manufacturers of the vehicles and the railway administrations.

SKF C-type spherical roller bearings are bound to accelerate the present trend towards more rapid rail transport with a high degree of reliability combined with low working costs.

[625 .24]

Competition for ideas on the wagon of the future,

first stage of an active and assured collaboration between the railway and the rolling stock manufacturers.

Note received from the INTERNATIONAL RAILWAY UNION (U.I.C.) — RESEARCH AND TRIAL DEPARTMENT (O.R.E.).

As far back as 1951, at the same time as through the intermediary of its Research and Trial Department (O.R.E.), the International Railway Union (U.I.C.) standardised constructional types of wagons on well known and well proved designs in order to constitute rapidly a homogeneous « EUROP » stock, capable of giving at very short notice all the advantages expected of « pooled » working; they also insisted on the necessity for the railways to modernise their stock periodically and at more frequent intervals than in the past, and expressed the wish that the Administrations should study the possibility of designing stock intended to have a shorter life than the usual 40 to 50 years, currently taken as the service live of wagons, naturally without upsetting the financial economy of the operating, but on the contrary endeavouring to improve it.

This wish and this new tendency were discussed with the builders in the O.R.E.-INDUSTRY conferences instituted by O.R.E. with the object of developing closer and more active collaboration with the rolling stock manufacturers. This was to a certain extent at the back of the « *Competition for ideas on the wagon of the future* », which was announced in the spring of 1954 in the U.I.C. Bulletin and in many of the technical periodicals.

The actual idea of the competition and the acceptance of industrial competition which it implies are due to the courageous initiative of the International Association of Rolling Stock Manufacturers (AICMR).

The railways welcomed the idea very warmly and agreed to support the competition by offering prizes, not very large ones but sufficient to create a spirit of emulation. The conditions of the competition were then listed by the O.R.E. and agreed with the AICMR; the manufacturers were given a year in which to study their entries.

Nineteen firms from 6 different countries took part in the competition, each being allocated a number as a pseudonym.

A mixed Jury consisting on the one hand of 5 railway engineers from various countries of uncontested international standing as regards questions relating to the construction and maintenance of wagons, appointed by the O.R.E., and on the other hand 5 highly qualified engineers attached to firms manufacturing wagons, designated by AICMR, under the Chairmanship of M. Cuttica, General Vice Manager of the F.S. (1) then carried out an extremely detailed, objective and thorough study of the entries.

(1) Italian State Railways.

These were considered under four headings as defined in the competition conditions, each of which was attributed a coefficient of importance also decided in the conditions. To make the technical and economic angle of the competition quite clear, it is of interest to give here the definitions of the four headings as laid down in the conditions :

1. Reduction in the sinking fund for the capital invested divided equally over the whole service life of the wagon and the annual cost of periodic maintenance : coefficient 4.

2. Reduction in operating costs (for example by traction, economies made possible by a reduction in the tare of the wagon, or a reduction in the cost of accidental repairs) : coefficient 3.

3. Reduction in the service life of the wagon (possibility of speeding up the modernisation of the stock of wagons) : coefficient 2.

4. Other advantages of the proposals entered (for example advantages for railway clients) : coefficient 1.

The results of the Competition were officially announced during the 4th O.R.E.-INDUSTRY Conference at Utrecht on the 25th April 1956. The following prizes were awarded, according to the conditions of the Competition :

First prize of 60 000 florins to the Waggonfabrik Uerdingen A.G., Krefeld-Uerdingen (Germany).

Second prize of 25 000 florins to the « Etablissements Industriels Soulé », Bagnères-de-Bigorre (France).

Third prize of 10 000 florins to the « Etablissements Arbel », 24, rue du Rocher, Paris (France).

First supplementary award of 7 500 florins to M.A.N. Maschinenfabrik Augsburg-Nürnberg A. G. Werk Nürnberg, Nürnberg 2 (Germany) and to the « Usines Ragheno », Malines (Belgium).

Second supplementary award of 5 000 florins to the « Ateliers de Construction du Nord de la France », 54, avenue Marceau, Paris (France), and to

Christ. Olsson i Falkenberg A.B., Orrspelsvägen 38, Bromma (Sweden).

The most interesting ideas from the proposals submitted by the firms entering the competition also received honorary mention.

* * *

As soon as the results were announced, O.R.E. concerned itself with the way in which the railways would use these results in the future. To understand the decisions taken, it must be remembered that the Competition was above all a competition of ideas. These were very seriously judged and assessed by the members of the Jury, but it must not be forgotten that a Jury is often obliged to base its verdict not only on certain and well known facts but also on presumptions and probabilities.

When it is a question of technique, it is always experience that must have the last word. Consequently, it was necessary that such experience should be available as soon as possible. On the 26th April, a combined meeting of the Committee of Experts of O.R.E. for the standardisation of wagons, the Jury of the Competition and the technical managers of the firms which gained the three prizes made it possible to define straight away the bases of the future work to be undertaken in close collaboration between the railways and the manufacturers. It will be seen therefore that the Competition of ideas was not an end in itself but marked the beginning of some long term work which will cer-

tainly be difficult but also extremely fruitful in information for the railways. This work will involve several stages. In the first stage, trials on prototypes built according to the winning designs will prove if the hypotheses and calculations used are valid and especially if the strength of wagons designed in this way is sufficient.

These trials will also throw light on the respective advantages and drawbacks of rigid or diagonal-elastic frames, and make it possible to decide which type will be used in future solutions, a choice which may perhaps differ according to whether it is question of wagons with a closed-in body (covered wagons) or open body (tipper).

The second stage will constitute the actual study of the wagons of the future; this will be, to an extent never before known, a synthesis of all the most interesting parts of the proposals submitted for the Competition. New prototypes will be needed here again, in this second stage, before arriving at the design of the future which can be used for the new standard light weight types of more modern, and more economical wagons, both from the point of view of construction and maintenance, which will economically justify a shorter amortisation period than that required for the present types of wagons.

It is therefore to the standard wagons of the future that the railways should look, whilst continuing to build at the present time the standard wagons of classical design.

In ending, we should like to draw the attention of our readers to the character of European efficiency which from the very beginning has marked this common initiative of the railway and industry, a character which was retained and developed during all the work and which must continue in the future work that will follow this competition.

656 .224 (42)]

Mechanisation of railway ticket offices.

Range of ticket printing and issuing machines obviates need for pre-printed stocks : possibilities of saving time and staff and introducing punched-card accountancy.

(*The Railway Gazette*, January 6, 1956).

The modernisation and re-equipment plans for British Railways, together with staffing difficulties, are concentrating interest once more on the possibilities of mechanising ticket offices and particularly on the potential savings from the printing of tickets as required with the consequent elimination of preprinted stocks and simplification of accounting control. An article by Mr. R. J. Eaton, Assistant Superintendent, Operational Research Division, Research Department, British Railways, on the mechanisation of ticket issues was the subject of editorial comment in our issue of August 12, 1955.

A series of ticket printing and issuing machines covering most aspect of this problem and at least two of the « scopes » mentioned in the article referred to is marketed by Westinghouse Garrard Ticket Machines Limited, Chippenham, Wilst.

The most familiar of these is the « Rapid Printer » used at many London Transport stations and, to a more limited extent, by British Railways. The machine stands at either the left or the right of the ticket office window. It contains a number of printing units, each a small printing machine in itself, which are grouped side by side and controlled by a keyboard having a button for each unit. The keyboard is connected by a flexible cable only to the machine and can thus be placed in any convenient position. Each printing unit is fed from its own roll of blank ticket card. The card passes through a paper detector mechanism and between two pairs of printing rollers to a guillotine. This cuts off the complete ticket and lets it fall on to a conveyor belt which delivers it to the passenger.

The first pair of printing rollers forms part of a self-contained detachable and interchangeable print block and prints the letterpress and progressive ticket number but not the date. These print blocks are also provided with visible non-return counters for calculating the daily cash balance. They can be changed in a matter of seconds, thereby virtually increasing the capacity of the machines to cope with a variety of tickets which may be issued at different times of the day, such as early morning returns.

The second pair of rollers prints the date and transports the card the required length before the completed ticket is cut off by the guillotine. A light touch on the appropriate button is all that is needed for a ticket to be printed, numbered, dated, recorded, and delivered direct to the passenger in a fraction of a second. If the button is kept depressed, some 200 tickets a minute can be issued, but in practice the speed is limited by the time taken for a ticket purchaser to state his requirements, pay his fare, receive change, and so on.

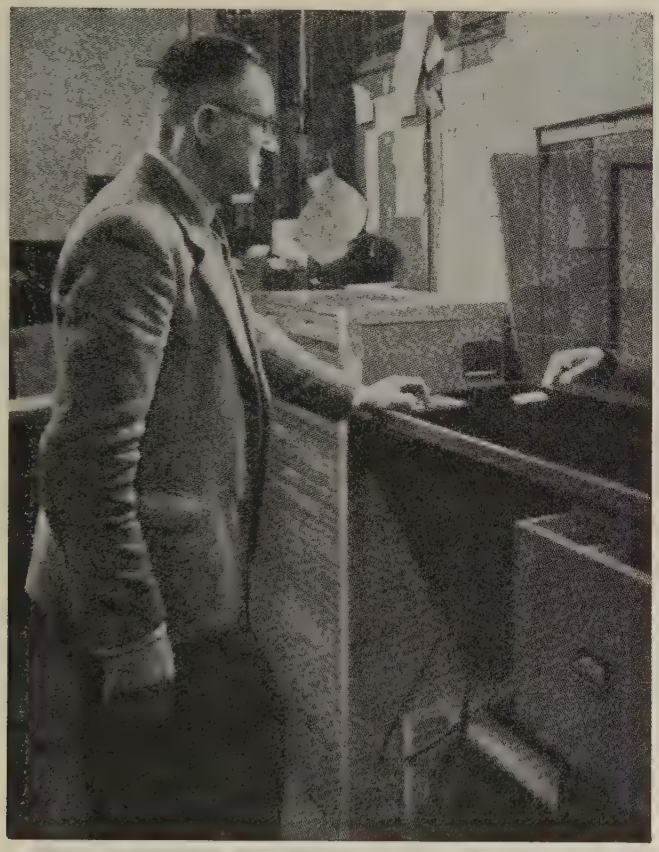
The standard machine is equipped with 10 printing units, but, in exceptional traffic circumstances, this size was found to be inadequate and 25-way machines were installed at Newcastle in 1931, followed some years later by 20-way on the former Mersey Railway.

The « Mini-Printer »

The « Mini-Printer » is a later development and really a smaller and simpler version of the well proved « Rapid Printer ». The conveyor belt and its associated parts have been eliminated and the tickets are ejected direct from each unit through a long slot at right angles to the ticket window. It is provided with printing units identical with those on the « Rapid Printer » and can be fitted with any number up to eight. The machine is small enough to be mounted on the ticket office counter.

A considerable number of Mini-printers is in service on London Transport and in all Regions of British Railways. Of the latter the greater proportion are in the Eastern Region. One of the latest installations has been made at Saltash in the Western Region where there is a very heavy demand for tickets to Plymouth, Devonport and St. Budeaux and queues have been virtually eliminated.

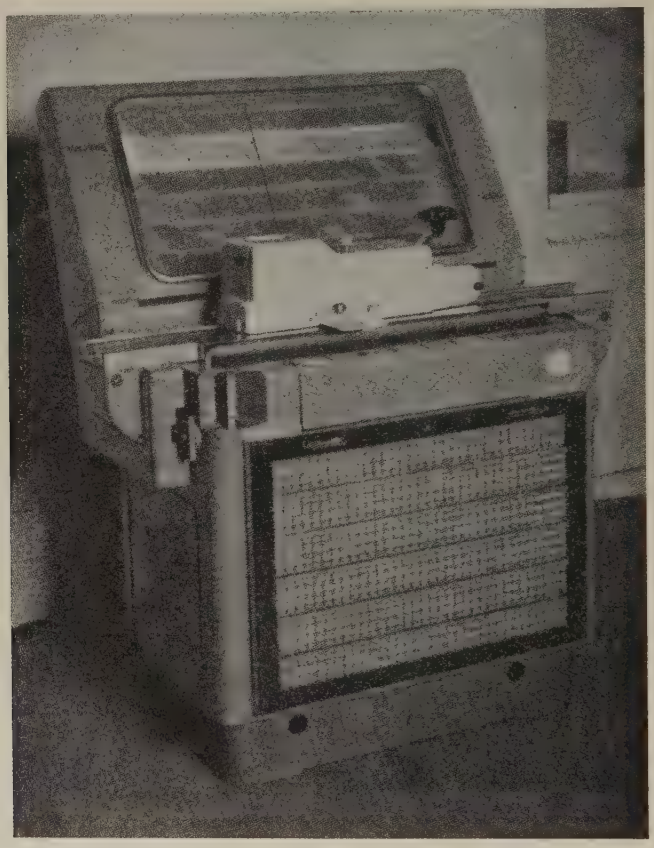
Both these machines adequately fulfil



The latest model of the « Rapid Printer » in use at a London Transport station. The ejected ticket is on the counter in front of the operating panel.

the requirements of scope 1, i.e., to meet conditions in which a large number of tickets of a limited variety has to be issued in a short time.

When dealing with scope 2, a different type of machine altogether is needed and one designed to meet these requirements and new to this country in its present form is the « Multiprinter ». Earlier versions of this machine are in use in many countries and an installation at the Gare St. Lazare in Paris was described in our issue of February 13, 1931. There is thus a considerable history of successful operation to draw on, including an installation at Liverpool Street which was brought into use on May 1, 1935, and described in our issue of May 3 of that year. The earlier types of these machines were put into successful service on the Continent as early as 1906.



The smaller model of the « Multiprinter », capable of printing and issuing 630 kinds of ticket. The statistical counters are behind the glass plate at the front.

The « Multiprinter », although rapid in operation, is designed to facilitate frequent, but not intensive, bookings of

many types of tickets to widespread destinations, and is thus in a different category from the machines already mentioned.

The machine was developed jointly with Allgemeine Elektrizitäts Gesellschaft of Germany, which has over 40 years experience in this type of equipment, and is handled in this country and certain other

ing and issuing 1 260 different kinds of tickets, and the Minor, which prints and issues 630 different kinds. Both machines have a height of 4 ft. 3 in. and are 1 ft. 8 in. from front to back. The Major model is 5 ft. wide and the Minor 3 ft. 6 in. The tickets are of regular Edmondson dimensions ($2\ ^1/_4$ in. × $1\ ^3/_{16}$ in.).

A « Mini-Printer » recently installed at Saltash Station, Western Region. The clerk's hand is on the operating panel.

specified territories by Westinghouse Garrard Ticket Machines Limited, which acknowledges the assistance of the Research Department of British Railways in an endeavour to incorporate as many features as possible to comply with British practice.

Wide range of tickets.

The « Multiprinter » is made in two sizes : the Major model, capable of print-

There is a main cabinet holding printing plates, with a movable printing carriage on top. In front is a bank of statistical counters, one for each plate, enclosed by a glass panel. At the rear of the main cabinet is a glass-fronted index panel on which the destination indicators are arranged in echelon form. This panel is inclined away from the operator for easier reading, and has coloured, translucent plastic buttons and station name

strips to provide a code for quick recognition. The panel is illuminated section by section horizontally as the printing carriage is moved. In the event of power failure the sections are indicated by a red arrow at the side of the printing frame. The printing carriage prints each ticket completely, including progressive number and date of issue, makes a detailed record of the transaction and adds to a totaliser the value of the ticket sold. The totaliser debit can be printed at any time by placing a special card strip in a slot at the left of the carriage and depressing a handle. A three-tiered cone on top of the carriage sets the date or can be used to exclude the date if required.

The printing plates, one for each type of ticket, are stored in troughs in the cabinet and are securely enclosed and absolutely inaccessible to the operator.

The « Multiprinter » provides complete security and if any of the protective devices is tampered with the machine will not operate. The plates are lifted by the printing carriage to print a ticket and then restored automatically to their proper place in the magazine.

Method of operation.

To print a ticket, the operator moves the carriage backwards or forwards until the appropriate section of the panel is illuminated and then slides the carriage sideways until a cursor line lies over the desired button. With practice, both movements can be carried out swiftly and simultaneously. A blank ticket card of the appropriate colour is then taken from one of 16 storage tubes at the front of the machine and inserted into a slot. This action operates the machine which instantly prints and ejects the ticket and makes the necessary records of the issue. If the electric power should fail the ticket can be printed manually by moving a lever on the printing carriage.

In addition to the plates stored within the machine itself, separate print blocks, usually available for use by all machines in an office, can be used by their being placed in a special slot on the left of the machine. Each block, or matrix, completely encloses a printing plate which is inaccessible to the operator. All the operations associated with a normal printing plate are carried out except that the statistical counter is on the front of the matrix itself and records the number of times it is used. This counter has to be read and manually recorded. When using such a matrix the operator is debited with the fare of the ticket issued on the records of his own machine.

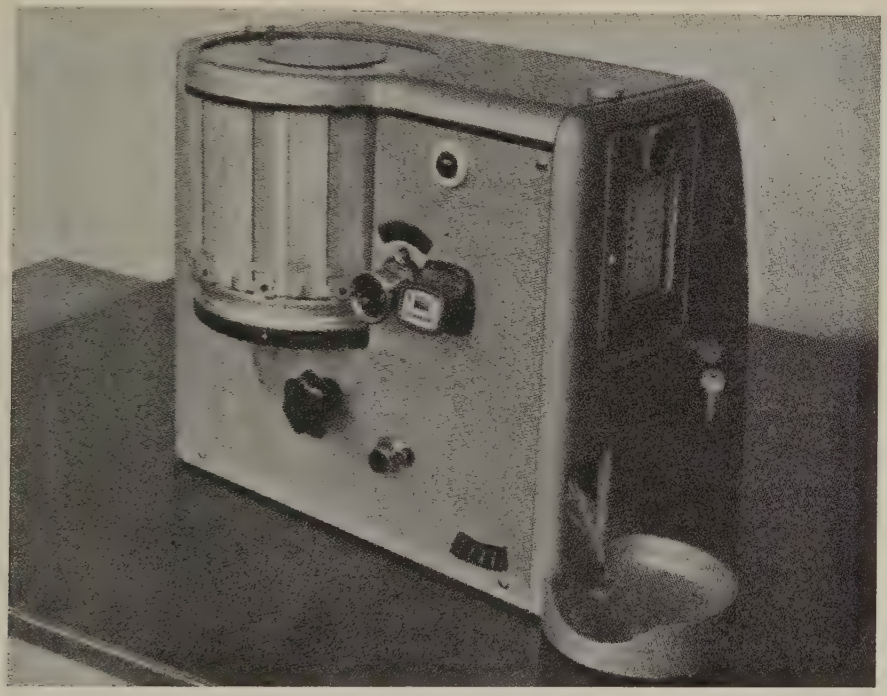
The detail strip in the printing carriage records, as each ticket is printed, the fare, printing plate number, and the progressive number of issue. The printing plate number enables the type of ticket, class, destination, and so on to be identified at once. The strip is $1\,^3/_8$ in. wide and moves as blank paper from a feed roll to the printing position, where it receives an impression at the time of issue of each ticket.

Printing plates.

The printing plates are some $3\,^1/_2$ in. $\times$ 2 in. and consist of a basic mount carrying permanent fare settings, one of which takes position on the ticket and the other, at right angles to it, on the record strip during printing. There is a printing piece which carries the wording of the ticket and also the printing plate number, which is aligned with the fare for printing on the record strip. If fares are revised, the printing piece can be removed from the basic fare mount and transferred easily to another mount carrying the new fare. An arrangement of pins in a perforated grid on the printing plate actuates the appropriate totaliser wheels.

There are as many statistical dissector counters as printing plates in the « Multiprinter ». Each time a plate is used its associated counter advances by one unit. A printed record of the state of the

counters can be made at any time by a special device which, running on guide rails, impresses on a paper strip, $1\,^{3}/_{32}$ in. wide, the identification numbers of the printing plates and the number of times each plate has been used. All necessary statistics can be compiled from this printed record, and the plate numbers provide a code on which the punched card accountancy to which this type of machine lends itself can be based. In ordinary working, a ticket clerk starts his day by printing for himself a special ticket, serially numbered, which shows the date, station name, and machine number. It has spaces for the clerk's name and his times on and off duty. He places a strip of card in the machine and prints the current debit. At the end of his shift he does the same and is responsible for the cash taken between the two balances. The clerk taking over performs the same operation and, provided that the two debits are taken consecutively, i.e., without sales of tickets intervening, there is no question of any balance having to be made for a handover between two clerks. If cash is being passed on, the total must, of course, agree with the printed debit. It is stressed that the mechanism of the machine cannot be interfered with in any way and records cannot be removed unless the proper keys, held by an authorised person, are used.



The « Flexiprinter » with a matrix inserted ready for operation. The ticket blanks are contained in the drum on the left.

New developments.

The « Multiprinter » lends itself to many situations, but yet a further machine will shortly be on the market designed

primarily to handle traffic at smaller stations. It is known as the « Flexiprinter » and has the additional advantage of being able to print and issue both standard Edmondson tickets and season tickets. Where heavy season ticket issues occur it could be used exclusively for that purpose, but the economic advantages of combining both facilities in one machine are apparent. The machine is no larger than a cash register and contains all the security devices and accountancy features embodied in the « Multiprinter ».

Its small size ($19\,^1/_2$ in. × 14 in. × 17 in.) is made possible by the fact that external cylindrical matrices are used, which are stored in specially designed racks immediately adjacent to the machine. These matrices are inaccessibly locked and are each provided with a printing plate, detachable fare piece, code block, cash totalisor segments, and statistical counter.

To operate the machine, the selected matrix is inserted and given a slight twist in a clockwise direction when the completely printed, numbered, and dated ticket is ejected immediately. If the matrix is held in the operative position tickets will be issued at the rate of 120 per minute. Simultaneously, the matrix code number, fare, and progressive ticket number are recorded on a detail strip and the amount of the fare is added to a cash totalisor.

As its name implies, this machine is so flexible in its applications that it can advantageously be installed in situations where even the smaller size « Multiprinter » cannot be economically justified. On the other hand it can be successfully used where the very high speed of a « Rapid Printer » or « Mini-Printer » is not essential but where the range of tickets of fairly high issue is greater than their limited capacity.

The range of machines described provides means for mechanising ticket offices for all grades of traffic, either by installation of one type or a combination of types to suit any variety of circumstances. They are the product of over 30 years specialised experience and are based on the belief that the most economic method of ticket issue is by printing at the point of sale, a maxim already put into effect by several administrations on the Continent.

621 .431 .72 (73) & 625 .2 (73)]

Aluminum on the Union Pacific,

by G. B. Hauser,

Head, Railroad Section, Sales Development Division, Aluminum Company of America.

(*Railway Age*, December 19, 1955.

Present-Day « City of Portland » has aluminum dome observation car, diner and coach as well as the standard coaches and sleepers which also are built with aluminum bodies.

America's new family of super-streamlined trains today has brought aluminum directly into the railroad spotlight as a passenger-car construction material.

Even as the new streamliners undergo final grooming for their maiden runs, aluminum is demonstrating that it offers a combination of properties desired for

high-speed, lightweight train construction.

How does aluminum perform in passenger car service over extended periods? This question can be answered by a look at the experience of the Union Pacific over the past 22 years. This road pioneered the use of aluminum rolling stock and is continuing to profit from its use.

The 1934 « City of Portland » was patterned after the original « City of Salina », but was equipped with a more powerful engine and two additional cars which contained the first sleeping accommodations in streamlined equipment.

The story of Union Pacific and aluminum began in 1933 with the building of the « City of Salina » — first of the high-speed lightweight trains. This was an all-aluminum (*) streamliner, using articulated cars and driven by a custom-built locomotive with a distillate engine.

This revolutionary experiment in aluminum construction was a marked success. Between 1934 and 1941 nine additional all-aluminum trains were put into service on UP and 50 coaches and diners were built for the railroad's « Challenger » coach train. Details on these trains are tabulated further on.

During the period from 1934 to 1941, the UP experienced a gradual transition in aluminum car construction. For two reasons, designers for the railroad gradually abandoned articulated passenger cars. First, they found passengers wanted more seating room in traveling UP's long runs than the original articulated cars offered. This objection might have been met without abandoning the articulated arrangement had not a second difficulty emerged from the use of auxiliary head-end power cars. Centering of power facilities in a single car permitted only one source of air-conditioning, lighting or heating. If the auxiliary power equipment went out, the whole train sweltered or froze, as the West's violent seasonal extremes dictated. Union Pacific's solution was to equip its long-haul cars with individual power. This modification, in itself, required a departure from complete articulation. (UP engineers consider articulated cars quite practical on shorter high-speed runs, where power car maintenance is less critical.)

For a while, a modified articulated car or twin-car was employed. It had three trucks, the two end trucks being equipped with four wheels. The center, where the two sections met, was supported by six-wheel truck. A number of these semi-articulated units which have individual power facilities are still in service.

Through this transition to individual 85-ft cars, aluminum was the prime building material for the entire train, including superstructure and floor. Only one difficulty arose with the light metal — and that involved the center sill and other underframe members. The importance in using aluminum for the center sill is obvious, since it affords a weight saving of about 3 000 lb. To meet Association of American Railroads' specifications, an aluminum-copper alloy was used for the center sill. Waste from car lavatories com-

(*) The only steel components used in the « City of Salina » were the bolsters.

bined with dirt from the roadbed to make a poultice-like covering. Corrosion set in beneath the coating. In diners, this was accelerated by salt and strong alkaline solutions. Consequently, steel underframes replace aluminum in later designs.

In spite of this situation some cars, including several diners, are still in service with their original aluminum underframes. Here adequate protective measures were employed. Generally, they involved painting the underframes and applying an undercoating similar to that used on automobiles. Spouts on the waste disposals were made longer to drop refuse closer to the ground. It was thus possible to maintain the weight savings advantage of aluminum underframe.

The use of aluminum underframes currently would probably be successful by using an alloy with high resistance to attack — Alloy 6061-T6. This has been blocked during recent years by an AAR specification which states that car structural material yield strength must not be greater than 80 % of its ultimate strength. This « spec » was designed to insure ductility in specified steel alloys, but actually does not serve that purpose with aluminum or even with some steels. Efforts are presently being made to correct this situation.

On the « City of Salina », this problem with underframes was not encountered since the aluminum longitudinal structural beams were protected by the fully enclosed « belly » of the train. In fact, when the train was retired in 1941, it was judged that it might have remained in service indefinitely. Commenting upon the retirement of the « City of Salina » to Aluminum Company of America officers, W. M. Jeffers, then president of the UP, made the following report :

« This train was powered with a 600-HP internal combustion engine and, of course, the power car housing this power plant was designed and built to accommodate this particular engine, and so the train was retired for the following reasons :

» 1. The power plant was practically worn out, and as this type of power plant is no longer in use, it was practically impossible to restore it; and to have installed a Diesel power plant in lieu of this 600-HP internal combustion engine would have necessitated completely rebuilding the power car at prohibitive cost and at a time when the expenditure could not be justified and materials for such construction not available.

» 2. The train lacked capacity to handle the increased local work in that territory brought about by the numerous war projects constructed or in the course of construction in that territory.

» 3. It has been the policy of the UP for many years to retire rolling stock not needed.

» 4. There being no longer a real need for this particular train, there could be no justification for tying the train up indefinitely at a time when there was an extreme shortage of aluminum.

» 5. Had it not been for the shortage of this critical war material, the train, when it was retired, would have been housed in our museum.

» You will be interested in knowing that the condition of the equipment at the time the train was retired was such that it fully supported the view I held at the time this lightweight train was under construction, that where a railroad was going to the extreme in reducing weight, aluminum was more durable and more practical than any other type of metal. So far as the condition of the cars was concerned, the train could have been continued in active service indefinitely.

» The announcement of the placing of an order for the construction of this first streamline train was made on May 24, 1933, which was approximately the low point in the business depression. Within less than nine months the train was an actuality. It was delivered on Febru-

Cafe-Lounge Car is typical of many standard cars that the Union Pacific has built through the years since 1933 using aluminum alloy body and roof.

Only operator of complete dome dining cars, the ten Union Pacific diners built by ACF this year have continued the use of aluminum. These cars are in service on the « Cities » of Los Angeles and Portland.

ary 12, 1934. A few days before a year had passed from the date of the original announcement, the train had completed a tour of the nation, during which a million and a quarter people had passed through the train and several more millions had seen it from station platforms, highways, etc., along route.

» After a successful experimental performance record of nearly 13 000 miles of practical operation, the train was then one of the principal attractions at the « Century of Progress » in Chicago until November of that year. The tour of this train, designated from its inception as « Tomorrow's Train Today », began with

its inspection first by President Franklin D. Roosevelt on February 15. The route which was followed on the tour was determined upon as providing a practical test of the possibilities of this new character of equipment. That route took the train over the rails of 14 different American railroads in 22 different states.

» The total mileage of this train during the period in service, or from January 31, 1935, to December 16, 1941, was 899 113 miles.

» Total gross revenue earned during the same period was $ 717 685.

» Original cost of the train was $ 230 997. »

Aluminum in current day cars.

The average new coach recently built for the UP is a big unit weighing approximately 136 000 lb. The entire superstructure is aluminum except for the collision end posts and bolster cripple posts, which are steel. With aluminum to lighten the load, the UP uses a heavy underframe. Exemplifying this heavy construction is the end platform and bolster casting, each of which weighs approximately 5 000 lb. This type of construction was designed to provide maximum safety.

The use of aluminum in UP car design was mainly responsible for making possible the safety features. Aluminum's lightness allowed more weight to be put into steel parts without excessively increasing total weight. Also, the aluminum side and roof sheet employed in the car construction was made much thicker than the steel sheets formely used. This thickness provides much more resistance to denting and collision damage. It is interesting to note that an aluminum sheet 40 % greater in thickness than a similar steel sheet still weighs only half as much.

Union Pacific states that the use of aluminum allows weight savings of 20 000 lb per car and allows the use of thicker sheet and structural members. This permits its trains to carry one or two extra cars on steep western grades.

Union Pacific engineers also look on weight saving in terms of horsepower economy. Since it is estimated that one horsepower is required for each 500 lb of car weight, the 20 000 lb saved on the average car reduces horsepower requirements by 40 per car.

Approximately 450 aluminum-steel cars are in service or on order. These include the UP's new dome-cars assigned to passenger, lounge and diner service.

An average of 18 000 lb of aluminum is used in current UP passenger cars. This is used in the superstructure, finish and trim of the car.

Maintenance and repairs.

An outstanding advantage of aluminum construction in trains is the ease of maintaining and remodeling cars, as well as repairing those damaged in derailments. Union Pacific has verified these facts through extensive experience.

When a UP aluminum car has been damaged, the riveted or lock-bolted construction allows easy disassembly of damaged parts. Where a section is beyond repair it can readily be replaced by a new one.

Regular maintenance of UP aluminum cars is simple. Since the UP uses paint on car exteriors, this presents a paint maintenance procedure. Aluminum offers a good base for paint and protection lasts the life of the paint itself. When the paint is scratched there is no rust formation, to spread and remove still more paint.

Conclusion.

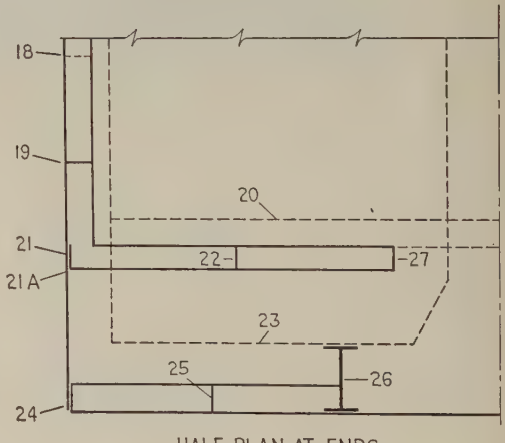
A number of conclusions of vital importance in the current re-evaluation of passenger service can be drawn from Union Pacific's aluminum train experience. Probably the most important was found in W. M. Jeffers' analysis of the retired

Location of aluminum components is shown in diagram (right) of typical Union Pacific passenger car construction.

	Alloy	Description or location
1	— ALC.2024-T3	Roof sheet
2	— 6061-T62	Carlines—double
2A	— 6061-T62	Carlines—single
3	— 6061-T62	Purlines
4	— 2014-T4	Side plate—two angles
5	— ALC.2024-T3	Letterboard sheet
6	— 6061-T62	Window header
7	— ALC.2024-T3	Pier panels
8	— 2014-T4	Belt rail inside outside
8A	— 2014-T4	Belt rail at letterboard
8B	— 6061-T62	Belt rail between posts
9	— ALC.2024-T3	Girder sheet
10	— L.A.H.T.	Side sill
10A	— 6061-T62	Auxiliary side sill
11	— 6063-T5	Skirts
12	— L.A.H.T.	Floor beams
13	— L.A.H.T.	Cross bearer
14	— Cast steel	Bolster
15	— L.A.H.T.	Center sill—AAR-Z26
16	— Stainless	Floor support on center sill
17	— L.A.H.T.	Floor stringers
18	— L.A.H.T.	Cripple posts at jacking pads
19	— 6061-T62	Side posts
20	— Cast steel	Body end sill
21	— 6061-T62	Body corner post—vestibule end
21A	— 6061-T62	Body corner post—vestibule end
21B	— 6061-T62	Body corner post—stub end
21C	— 6061-T62	Body corner post—stub end
22	— 6061-T62	Intermediate end posts
23	— Cast steel	Buffer beam
24	— 6061-T62	Vestibule corner posts
25	— 5052-H32	Vestibule intermediate end posts
26	— Steel	Diaphragm post
27	— 6061-T6	Door post

General: Riveted construction. Steel rivets at side plate and side sill. All other connections aluminum rivets or aluminum lockbolts.

HALF CROSS SECTION



HALF PLAN AT ENDS

Train	Number of cars and type	Aluminum construction	Total amount of aluminum lb	Approx. amount aluminum per car lb	Average length of car, ft-in	Described in Railway Age
City of Salina M 10 000	3 (articulated)	All aluminum except bolsters	65 870	23 000	67-6	Feb. 3, 1934, p. 184
City of Portland, variation of M 10 001	5 (articulated)	All aluminum except bolsters	162 691	32 500	65-0	Oct. 13, 1934, p. 427
City of Los Angeles M 10 002	9 with two power cars (articulated)	All aluminum except bolsters and cross-bearers	292 500	32 500	64-0	May 30, 1936, p. 864
City of San Francisco M 10 004	9 with two power cars (articulated)	All aluminum except bolsters, cross bearers, jacking beams and end sills	288 000	32 000	66-0	May 30, 1936, p. 864
City of Denver M 10 005	12, of which two steel power cars (articulated)	All aluminum except bolsters, cross bearers, jacking beams and end sills	322 267	32 200	72-0	July 4, 1936, p. 4
City of Denver M 10 006	12, including two power cars (articulated)	All aluminum except bolsters, cross bearers, jacking beams and end sills	322 267	32 200	72-0	July 4, 1936, p. 4.
City of Los Angeles	14 (no power cars)	All aluminum except bolsters, cross bearers, jacking beams and end sills	298 465	21 320	75-6	Jan. 29, 1938, p. 224
City of San Francisco	14 (no power cars)	All aluminum except bolsters, cross bearers, jacking beams and end sills	298 465	21 320	77-2	Jan. 29, 1938, p. 224
City of Los Angeles and City of San Francisco	37	All aluminum except bolsters, cross bearers, jacking beams and end sills	824 428	22 280	84-9	.....

« City of Salina ». His statement reads :

« Where a railroad was going to the extreme in reducing weight, aluminum was more durable and more practical than any other type of metal. So far as the condition of the cars was concerned, the train could have been continued in active service indefinitely. »

The use of aluminum by the UP in both articulated and individual car design has proved that the light metal can be used with equal success in both types.

The conclusions on the life and maintenance of aluminum rolling stock are good. The growing pains have been overcome; and the proper alloys of light metal offer railroads an invaluable building material for passenger trains of the future.

M. WEISSENBRUCH & Co. Ltd.
Printer to the King

(Manag. Dir.: P. de Weissenbruch,
238, chaussée de Vleurgat, XL)

PRINTED IN BELGIUM

Edit. responsible : P. Ghilain